CONDENSED MILK

A STUDY OF CONDENSED, EVAPORATED, AND POWDERED MILK

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PREFACE

Since this book by a Japanese author is being published in the United States it may be worth while to tell English-speaking readers something about the author and his work.

Doctor Miyawaki was introduced to dairy science at the Kansas State Agricultural College, Manhattan, Kansas, under Professor Oscar Erf, now head of the Department of Dairying at Ohio State University. Professor Erf early recognized his possibilities, from the intelligence, care, energy, and enthusiasm shown in his work and after proper preparation selected him as one of the assistants in Dairy Investigational Work. At Kansas State Agricultural College he received both the bachelor's and the master's degrees.

After his return to Japan he became connected with the College of Agriculture at Sapporo, which has since developed into the Hokkaido Imperial University. The region of northern Japan in which Sapporo is situated much resembles in climate the dairying district of New York State, and the development of the dairy industry there is greater in proportion to population than in any other part of the Empire. This is largely due to the pioneer work of the College, which has a fine herd of cattle on its own farm adjacent to the campus. Both laboratories and dairy equipment are provided, and students have every opportunity to become versed in all phases of dairying, both theoretical and practical.

In addition to directing this work at the College, Doctor Miyawaki early became interested in a milk condensery in Sapporo, and caused elaborate records to be kept of all the data entering into the problem of manufacturing sweetened condensed milk. As professor of another subject in the same Department of Animal Industry, I had the privilege of being

associated with him for three years, and so learned much about his work. When he made a digest of the vast mass of condensery data as part of the thesis submitted for the degree of Doctor of Agricultural Science, I examined it with great interest.

Doctor Miyawaki's work in dairy science has not been limited to condensed milk. He has touched all parts of the field and done distinguished work in several sections. Some idea of the keenness and skill which he brings to bear on all problems may be gleaned from various parts of this book, especially that on the properties of powdered milk. He was a delegate to the World's Dairy Congress in 1923, and afterward visited the important dairy countries of Europe, studying cattle and dairy practice. He is recognized as one of the chief authorities on dairy science in Japan.

My share in this book consists only in helping to prepare it for the press, a matter of some concern when the author is on the other side of the world. This share has been a source of pleasure for several reasons, chief among which is the opportunity it affords to discharge some part of the debt due to Doctor Miyawaki for the help which he gave most cordially on many occasions, and without which my own work at Sapporo would have been almost impossible.

The book has had the advantage of Professor Erf's examination and criticism, for which both author and editor are grateful.

LLOYD BALDERSTON

WILMINGTON, DELAWARE

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INTRODUCTION

MILK, butter, and cheese have been in use since prehistoric times, notably among the Egyptians. Gautama Buddha is said to have maintained his vigorous health by the use of milk and milk products, although he ate no meat. The Japanese in ancient times used milk and butter, principally as medicine. In contrast to butter and cheese, which have been made from time immemorial, condensed milk is of recent origin; but its various forms have now assumed a position of importance among dairy products. As an article of commerce, it may be said to have originated near the middle of the nineteenth century, although a Japanese process for making a product like unsweetened condensed milk, with a very low water content, was in use as long ago as the seventh century.

Especially since the discovery of vitamins, the value of milk as a food has been well known and widely appreciated, so that in many countries it is in daily use in most households. Perhaps the cheapest well-balanced meal consists of bread and milk. The annual per capita consumption of milk, butter, and cheese in various countries is given in the following table, the figures denoting avoirdupois pounds.

MILK

Sweden	558	Switzerland	539	United States	420
Belgium	352	Germany	488	Hungary	194
Holland	316	Canada	208	United Kingdom	178
Italy	34	Denmark	548		

BUTTER

Canada	8	Denmark	22	Australia	26
United States	19	Holland	17	United Kingdom	17
Sweden	17	Germany	15	Switzerland	12
Norway	14				

Cheese

Switzerland	26	Holland	13	Denmark	12
Germany	10	France	8	United Kingdom	11
Norway	7	Italy	5	Australia	5
United States	4	Canada	3	New Zealand	3

Statistics in regard to the consumption of condensed milk are in general lacking. In consequence of the World War a considerable amount of condensed milk has been used in recent years in European countries as a substitute for fresh milk. In Oriental countries condensed milk is an important infant food. In the United States much unsweetened condensed milk is used in the manufacture of ice cream.

Milk powder is now making its way in the market. Lack of keeping quality has hindered its use, but recent inventions have improved it in this respect, and the consumption of milk powder is increasing. In Germany an artificial milk is prepared from it by using homogenizers to incorporate cocoanut oil with American and Australian milk powder. A substitute cream made from cocoanut oil and skimmed-milk powder has been sold in Germany since the War. Milk powder has also come into use as a filler in ice cream, though in some places the authorities object to its use for this purpose. Milk powder is also finding wide use in infant foods, either alone or in combination with other materials.

Milk beverages, such as "kefir," "yoghurt," "kumiss," etc., are among the oldest of milk products. While their use is rather limited, they are found in many parts of the world. In France, yoghurt is found in most restaurants. In Switzerland, kefir and yoghurt are delivered along with city milk.

Ice cream is no longer a luxury. Its consumption, especially in America, is rapidly increasing. It is now used not only in hot weather but all the year. The electric refrigerator and the invention of chocolate-coated ice cream have helped to extend the market.

Many of the inhabited parts of the world are, for one reason or another not adapted to dairying. Because milk does not keep well, and because its volume is relatively great, it can be distributed in its natural state only within rather small distances from the place of production. In order to furnish milk to people living outside of dairy regions, a process which prevents

deterioration and diminishes the volume has been invented. A thick fluid product, with or without sucrose or maltose, is called condensed milk or concentrated milk. A nearly dry product, usually in powdered form, is called desiccated milk or milk powder. While there is much valuable literature on many subjects connected with dairying, the published data in reference to these products are few. The author therefore aims, in this treatise, to give his experience, along with many data about milk, obtained from various sources.

CONDENSED MILK

CHAPTER I

THE CONDENSED MILK INDUSTRY

EUROPEAN records show that experiments on the manufacture of condensed milk were made by Appert, De Heine, Newton, Grimwade, Horsford, Dalson, Gallois, and Deauve. Newton added 1 or 2 per cent of sucrose to the fresh milk and evaporated it in a jacketed pan, blowing hot air through. He also experimented with evaporation under partial vacuum.

In 1849 Martin Deiignac tested the effect of evaporation on milk constituents and found that they suffered little change. In 1867 Liebig introduced the idea of using condensed milk for infant feeding, and gave a recipe for the preparation of the food. The value of this method of feeding infants was denied by influential physicians, including Guiborg, Poggiale, and Depaul. Liebig's so-called "artificial milk" was thus discredited and the manufacture of condensed milk discouraged.

It was only when Gail Borden, in 1858, with the financial support of Jeremiah Milbank, founded the New York Condensed Milk Company, that the manufacture of condensed milk was thoroughly established on a sound business basis. Gail Borden had long studied the problem, and in 1853 had applied for a patent which was granted in 1856. He was able at that time to produce condensed milk of very good quality, but the demand for it was small. This and other conditions resulted in the failure of his first venture as a commercial enterprise.

After Gail Borden had succeeded, Page Brothers established a successful condensery in Europe in 1866, under the name of the "Anglo-Swiss Condensed Milk Company." Later it was ab-

sorbed by the Nestlé Condensed Milk Company, and in 1904 the name became "Nestlé and Anglo-Swiss Condensed Milk Company." This company now has factories in all parts of Europe and in the United States and Australia, and holds the right to export Borden's products to the Orient.

In Australia, John Fell made an extended study of the manufacture of condensed milk, and in 1886, with the financial support of Sir John Hay, he established a factory. This enterprise was not a success. The first condensery to succeed in Australia was that established in 1890 at Bacchus Marsh in Victoria, by

Courtesy of the Nestlé and Anglo-Swiss Condensed Milk Company.

FIG. 1.—ANGLO-SWISS CONDENSED MILK COMPANY'S FACTORY AT CHAM, SWITZERLAND IN 1866.

The first condensed milk factory built in Europe.

the Bacchus Marsh Concentrated Milk Company. Following this success, many small factories were set up in various parts of Australia, but most of them were financial failures. About 1909 the Nestlé and Anglo-Swiss Company invaded Australia, buying a factory at Cressbrook, Queensland, which was the first to make a success of the sweetened condensed milk industry in Australia. They soon enlarged the plant, and established others in different parts of the country.

In Japan, as has been mentioned, a kind of concentrated milk was made in the seventh century, but it was very different from

modern condensed milk and never had any industrial importance. The first serious attempt to manufacture condensed milk in Japan was made in the sixties of the past century, under the care of a governmental department. In the seventies, the Hokkaido Colonial Government made an attempt at Makomanai Live Stock Breeding Station. In the eighties, the Imperial Stock Farm at Shimoosa made experiments. The Agricultural College at Sapporo, now Hokkaido Imperial University, was at this period giving much attention to experiments and was instructing its students in the making of condensed milk.

Courtesy of the Kyokuto Condensed Milk Company.

FIG. 2.—DAIRY FARM IN JAPAN.

The dairy industry in Japan is growing rapidly as a result of the establishment of condensed milk factories.

In the nineties, private establishments were at length started, first in Shidzuoka and Chiba, and later in Hokkaido, Osaka, Fukushima, and elsewhere. Most of these attempts failed. Hyoemon Hanajima was probably the first private manufacturer in Japan to achieve success, and he was the first Japanese to use a vacuum pan in the process. The Junsen Stock Farm of Fukushima was among the early successful makers of condensed milk.

To Japanese dairymen the problem of disposing of surplus milk from their city supplies was a serious problem, and many of them, early in the twentieth century, turned to condensed milk as a solution. Some were driven out of the business by the heavy

consumption tax levied upon sugar in 1901. Because of the war with Russia in 1904–05, an emergency tax was placed upon sugar, and this caused the closing of other factories. In 1908, in order to encourage the industry, the consumption tax on sugar was refunded to those using sugar for making condensed milk, and this policy has been continued. In 1911 the import duty on condensed milk was raised to 5.55 yen per 100 kin (about 133 lbs.), receptacles included. In 1913 newly established factories were exempted from income tax.

The Japanese Government has made every effort to develop the industry, and the Department of Agriculture and Commerce has sent out specialists to lecture on improved methods of manufacture, thus encouraging beginners to better their product. The College of Agriculture of Tohoku Imperial University (now Hokkaido Imperial University), at Sapporo, has installed equipment for the manufacture of sweetened condensed milk, and careful and long-continued investigations have been carried out under the direction of Professor Sagoro Hashimoto.

CONDENSED MILK INDUSTRY IN THE UNITED STATES

Since Gail Borden built his first factory at Wolcottville in 1856 the industry has grown rapidly and now occupies an important place in the dairy industry of the United States. Formerly the Borden Company made only the sweetened product. In 1885 the Helvetia Company made its start in the manufacture of unsweetened condensed milk, with John B. Meyenberg, patentee of the process, as factory director. The industry has grown rapidly, and now the production of unsweetened condensed milk far exceeds that of the sweetened product. The growth of the condensed milk industry is exhibited in the table, page 5.

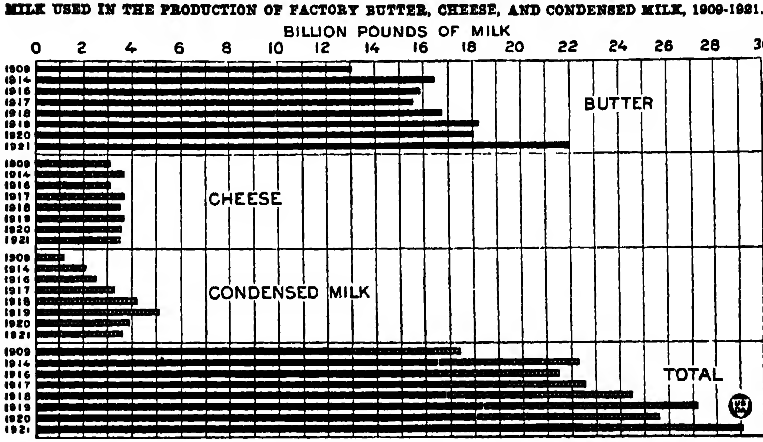
The diminution after 1919 resulted from decreased demand after the War. The total number of pounds of milk used in 1921 for making condensed milk was 3,660,408,000, about 3.7 per cent of the total milk production of the country. In 1904 unsweetened condensed milk made up about one-third of the total, while in 1919 the proportion had risen to about two-thirds. This is in large part due to the use of the unsweetened product in making ice cream.

PRODUCTION OF CONDENSED MILK IN THE UNITED STATES

(Thousands of Pounds)

Year	All Kinds	Condensed	Powdered	Powdered Skimmed
1899	186,921			
1904	308,485			
1909	494,797			
1914	883,113			
1919	1,843,778			
1921	1,464,163			
1922	1,431,349			
1923		1,774,881	6,560	

MILK USED IN THE PRODUCTION OF FACTORY BUTTER, CHEESE, AND CONDENSED MILK, 1909-1921.



Prepared by the United States Department of Agriculture.

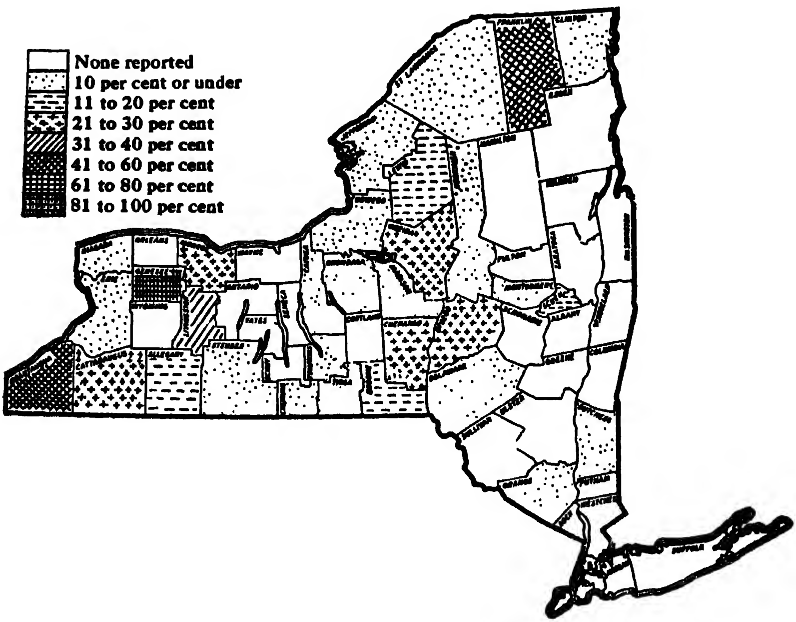
FIG. 3.—MILK USED IN THE PRODUCTION OF FACTORY BUTTER, CHEESE, AND CONDENSED MILK, 1909–1921.

This graph was made on the basis of 21 lbs. of milk per pound of butter, 2½ lbs. of milk per pound of condensed milk, and 10 lbs. of milk per pound of cheese. The United States is the largest producer of condensed milk.

In 1919 condensed milk was made in thirty-four states. Wisconsin produced most, New York coming next. In sweetened condensed milk, however, New York leads, with 333,316,000 lbs. of the whole-milk and 2,696,000 lbs. of the skimmed-milk product in 1919, as against 55,303,000 and 4,792,000 lbs., respectively, for Wisconsin. Illinois comes next to New York in its output of the sweetened product, with 67,528,000 lbs. of whole and 7,250,000

lbs. of skimmed. In this list Michigan comes third and Wisconsin fourth, with Pennsylvania nearly equal to Wisconsin.

In round numbers, 5 billion lbs. of milk were received from farmers in the State of New York in 1922 by the milk plants reporting to the Department of Farms and Markets. This includes milk of which only the cream was received. About 3 billion lbs. were marketed as fluid milk, cream, and ice cream;



Prepared by the Department of Farms and Markets of the State of New York.

FIG. 4.—MILK USED FOR CONDENSED MILK IN THE STATE OF NEW YORK.

The State of New York alone produces more condensed milk than any nation except the United States, but the milk used in this industry is only 123 per cent of the total receipts at various plants.

600 million as butter; 600 million as condensed and evaporated milk; and 600 million as American cheese. Most of the remaining 200 million lbs. was used for cheese of other than American types.

The greater part of the condensed and evaporated milk is produced in counties which are comparatively remote from markets for fluid milk and which have a greater production in summer than in winter. Nearly four-fifths of the total output

of condensed and evaporated milk is packed in small cans for the retail trade and is known as case goods. The rest is sold in bulk, mostly in 40-quart cans or in barrels, for use in bakeries and in making candy, ice cream, etc. The production of the various kinds of condensed milk in New York in 1922 is shown in the following table.

ANALYSIS OF CONDENSED MILK PRODUCTS IN NEW YORK, 1922

Kind	Quantity, Thousands of Pounds	Per Cent of Total
Sweetened condensed:		
Unskimmed (case goods)	92,257	31.3
Unskimmed (bulk goods)	3,211	1.1
Skimmed (bulk goods)	7,975	2.7
Unsweetened condensed:		
Unskimmed (bulk goods)	41,845	14.2
Skimmed (bulk goods)	6,722	2.3
Unsweetened evaporated:		
Unskimmed (case goods)	139,985	47.6
Unskimmed (bulk goods)	1,739	0.6
Skimmed (bulk goods)	701	0.2
Total	294,435	100.0
Total unskimmed (case goods)	232,242	78.9
Total unskimmed (bulk goods)	46,795	15.9
Total skimmed (bulk goods)	15,398	5 2

The total value of dairy products sold by New York dairy plants in 1922 is estimated at $168,855,000, of which condensed and evaporated milk amounts to more than $33,000,000. The value of fluid milk and cream accounts for somewhat less than $100,000,000, from which it appears that the condensery products form nearly one-half of the manufactured milk products.

In spite of the great volume of her dairy products, the United States is not, on the whole, an exporting country, production and consumption nearly balancing. She imports cheese and exports condensed milk in the form of case goods. The decrease

in foreign consumption of these goods after the War accounts in large part for the decrease in production of condensed milk after 1919. The following table shows the increase in exports during the War and the falling off that has occurred since.

EXPORTS OF CONDENSED MILK FROM THE UNITED STATES

(Thousands of Pounds)

Average	1910–1914	17,526	1920	414,250
	1919	728,740	1922	299,172

In consequence of the decrease in foreign demand, some factories have closed and some have been changed into cheese factories. In 1922 there were 422 factories in thirty-two states. The following table shows their distribution.

New York	89	Maryland	4
Pennsylvania	54	Missouri	4
Wisconsin	54	New Jersey	4
Ohio	38	Idaho	3
Illinois	35	Utah	3
Michigan	32	New Hampshire	2
Washington	19	Virginia	2
California	15	West Virginia	2
Kansas	10	Alabama	1
Indiana	8	Arizona	1
Minnesota	8	Georgia	1
Oregon	7	Kentucky	1
Nebraska	6	Maine	1
Vermont	6	Massachusetts	1
Colorado	5	North Dakota	1
Iowa	4	South Dakota	1

One hundred and eighty-eight firms in the United States manufacture condensed milk and kindred products. Some of these firms have no trademarks; others market their products under several. In all, there are about 176 trademarks in the United States.

CONDENSED MILK INDUSTRY IN CANADA

Canada has long been known as a dairy country and is noted for her export of cheese. There have been important changes

in her dairy industry. While her production of cheese diminished from 220,833,000 lbs. in 1900 to 134,530,000 in 1922, in the same time her butter total rose from 36,067,000 to 146,864,000 lbs., and her condensed milk from a value of $269,520 to $6,839,000.

The first condensed milk plant was established at Truro in 1883. In 1924 there were twenty-three plants, making various

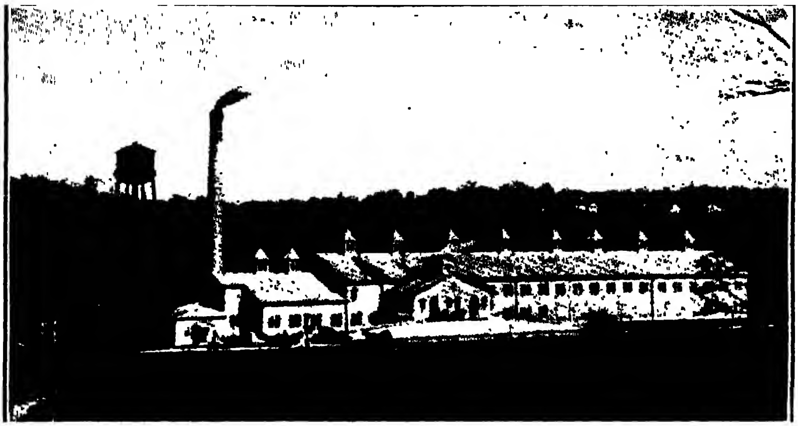


Fig. 5.—Canadian Condensed Milk Factory, Tillsonburg, Ontario

kinds of condensed products. A table showing the production in recent years follows.

Canadian Condensed Milk Production

(Thousands of Pounds)

Product	1920	1921	1923
Condensed milk	53,663	38,998	77,984
Condensed skimmed milk	363	1,308	
Evaporated milk	30,470	31,203	
Milk powder	7,575	1,703	11,098
Skimmed milk powder		5,749	
Condensed coffee and cocoa	531	324	
Casein	110	98	
Sterilized milk	7 609	6,696	

Although mucn less condensed milk is produced in Canada than in the United States, its relative importance is greater. The value of the above items for 1921 is about $9,400,000, or 4.4 per cent of all Canadian dairy products.

Canada's exports of all dairy products except cheese have increased during the last ten years, over the preceding ten-year period, the most important increase being in condensed products. Figures for several years are given in the following table.

EXPORTS OF CONDENSED MILK FROM CANADA

Year	Thousands of Pounds	Value, Dollars
1916	13,248	770,500
1920	54,247	8,517,800
1921	49,147	8,188,000
1922	33,133	4,881,000
1923	26,381	2,861,000

The principal market is the United Kingdom, but much goes to other European countries, and some to Asia.

Establishments making condensed milk destined for export, either from Canada or from one province to another, are inspected under the Meat and Canned Food Act by officers of the Dominion Department of Agriculture. The regulations provide that the materials used shall be sound and wholesome; that containers shall be properly sterilized; that no deleterious drug, dye, or preservative shall be used; and that the labels shall show the name and address of the manufacturer and give a true description of the contents.

CONDENSED MILK INDUSTRY IN JAPAN

Largely as a result of the efforts of the Government and of educational institutions, twenty-seven condenseries had been established by 1911. This number had increased to thirty-three in 1912, and to thirty-nine in 1913. The total product for the year 1913 was only 2,900,000 lbs., valued at 560,800 yen (about $280,400). Many of the manufacturers were not sufficiently well informed or equipped to succeed, and so either became bankrupt or simply closed out.

Under these discouraging conditions the Hokkaido Condensed Milk Company, Limited, was established in Sapporo in 1914.

It installed up-to-date equipment and called to its aid the knowledge obtained at the College of Agriculture during many years. It was thus able to turn out a product which stood the most rigid tests and compared well with the best foreign brands. Just at this time the World War hindered the importation, not only of European, but even of American condensed milk, and the rise in prices attracted capital into the condensery business. Japan's favorable position in the industrial and commercial

Fig. 6.—A Condensed Milk Factory in Japan.

The Hokkaido Condensed Milk Company was established in 1914 at Sapporo, and has been in successful operation ever since.

world caused an accumulation of new capital seeking investment, with the result that the twelve limited stock companies and thirteen private and coöperative concerns which were in operation in 1919 were, on the whole, very well equipped and staffed. There was not milk enough to supply all the factories fully, and this fact, together with the financial crisis which came after the War, caused some companies to shut down, others to be reorganized, and a few to be consolidated. The production and value of condensed milk for Japan are shown in the following table.

Production of Condensed Milk in Japan

Year	Thousands of Pounds	Value, Yen	Index of Value
Average 1912–1916	3,894	789,231	100.0
1917	7,937	2,275,765	288.3
1918	10,820	3,688,262	467.3
1919	16,903	6,910,496	875.5
1920	12,815	5,831,701	737.8
1921	13,084	5,529,658	700.6
1923	16,210		
1924	16,448		
1925	18,428		

The production of raw milk has not kept pace with the increase in the manufacture of condensed milk, as is shown in the following table.

Production and Uses of Milk in Japan

Year	Milk Production, Thousands of Pounds	Approximate Amount Used for Condensed Milk	
		Thousands of Pounds	Per Cent
Average 1907–1911	93,607		
Average 1912–1916	115,085	9,735	8.3
1917	135,466	19,843	14.6
1918	134,478	27,051	20.1
1919	134,046	42,257	31.7
1920	140,997	32,286	22.9
1921	181,844	32,710	18.0

These figures show clearly the rising importance of condensed milk manufacture to the dairy industry of Japan. In the United States, where a great amount of condensed milk is manufactured, only 4 to 5 per cent of all the milk produced is used for this purpose, while 30 to 40 per cent is made into butter. The relative importance of the industry is therefore much less in the United States than in Japan.

The fluctuation of imports and exports is shown in the following table.

Japanese Imports and Exports of Condensed Milk

(Thousands of Pounds)

Year	Import	Export	Year	Import	Export
1908	10,910		1915	4,165	22
1909	10,611		1916	3,795	479
1910	10,793		1917	4,558	1,047
1911	9,121		1918	3,234	1,451
1912	9,281		1919	4,061	2,856
1913	6,970		1920	4,701	810
1914	5,784	44	1921	6,007	128
			1922	7,504	

Courtesy of the Kyokuto Condensed Milk Company.

Fig. 7.—Factory of the Kyokuto Condensed Milk Company at Sapporo.

The Kyokuto (Far East) Condensed Milk Company has branch factories throughout Japan. They also own the largest pure-bred Holstein herd in Japan.

The tendency toward decreased exports accompanied by increased imports, shown in this table for the later years, taken in connection with the figures for total Japanese production (13 million lbs. for 1921), shows an increasing consumption of condensed milk in Japan. The fall in imports after 1911, when Japanese production began, is significant.

CONDENSED MILK INDUSTRY IN EUROPE

While dairying is one of the most important agricultural industries in Europe, most European nations are importers of dairy products, Russia alone being entirely self-supporting in this respect. Sweden and Norway have long been known as dairy countries, yet they produce just about enough for home consumption. Denmark is famous for her dairy industry and

FIG. 8.—THE DAIRY, SWEDISH AGRICULTURAL COLLEGE, ALNARP.

Sweden is one of the oldest dairy countries. Now she produces just enough for her own needs.

exports butter to many nations, especially the United Kingdom. Danish farmers sell their milk to butter factories and sometimes buy oleomargarine for home use. It is astonishing to see more oleomargarine exhibited in Danish stores than anywhere else. Butter production is the specialty of Denmark, but cheese making has been introduced in recent years with some success, and since the World War the condensed milk industry has made a beginning.

DENMARK

Though essentially an agricultural country, Denmark is obliged every year to import several hundred thousand tons of grain in excess of her exportation. She is also a large importer of other

foodstuffs and fertilizers. Therefore, her chief income is from the export of butter and the allied products, ham, bacon, and eggs. Butter alone accounts for about 40 per cent of Denmark's agricultural exports. If to this be added other dairy products, eggs, hog products, cattle, and hides, the sum is 95 per cent

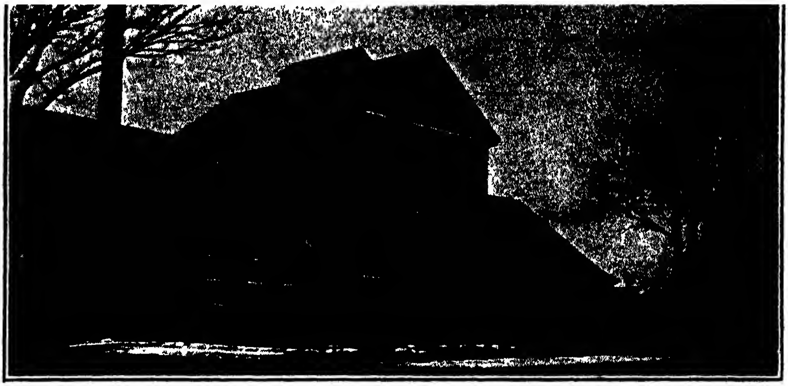


FIG. 9.—DANISH DAIRY MANUFACTURING EXPERIMENT STATION.

Denmark is the premier dairy country of the world. Her specialty is the production of butter. The condensed milk industry in Denmark began since the War.

of all her agricultural exports. A table follows showing exports of dairy products in recent years.

EXPORTS OF DAIRY PRODUCTS FROM DENMARK

(Unit of Value, 1000 Kr.)

	Average, 1910–13	1919	1920	1921	1922
Butter:					
Tons	88,300	35,600	74,800	92,000	95,500
Value	191,700	229,200	503,300	464,670	
Milk and Cream:					
Tons	30,400	4,600	9,100	2,000	350
Value	18,100	5,600	8,100	1,850	
Cheese and Casein:					
Tons	1,000	2,600	9,700	12,500	8,900
Value	580	8,300	23,300	21,050	

PRODUCTION OF MILK AND CONDENSED MILK IN DENMARK

(Thousands of Pounds)

Year	Milk	Condensed
1917	5,600,000	
1918	3,600,000	
1919	3,800,000	18,800
1920	6,000,000	30,000
1921	6,400,000	36,200
1922	6,800,000	

FIG. 10.—DAIRY CATTLE EXPERIMENT STATION, DENMARK.

HOLLAND

Holland is well known as a dairy country, her cheeses being famous the world over. In 1921 she exported 65,000 tons of cheese, about two-thirds of the total production. In the same year, butter was exported to the amount of 23,000 tons.

Figures for the production of condensed and powdered milk are not available, but exports are as shown in the following table.

EXPORTS OF CONDENSED AND POWDERED MILK FROM HOLLAND

(Thousands of Pounds)

Year	Sweetened	Unsweetened	Milk Powder
1917	103,894	1,591	8,595
1918	40,008	79	3,412
1919	31,599	644	9,540
1920	104,008	1,049	12,118
1921	147,580	3,830	11,547
1922	171,348	3,546	9,694

SWITZERLAND

The condensed milk industry of Switzerland is next in importance to that of the United States, not on account of the quantity produced, but for its historic interest and because of the relative importance of condensed milk in the Swiss dairy industry.

The first successful condensery in Europe was established in 1866 at Cham, on Lake Zug, by Charles A. Page, then American consul at Zürich. He, with his brother, George H. Page, founded the Anglo-Swiss Condensed Milk Company, with the support of English capitalists. This company was very successful and

Courtesy of the Nestlé and Anglo-Swiss Condensed Milk Company.

FIG. 11.—PLANT OF THE NESTLÉ AND ANGLO-SWISS CONDENSED MILK COMPANY, CHAM, SWITZERLAND, 1924.

This company is the largest condensed milk company in the world, having branch factories in many countries.

soon established many branch factories, not only in Switzerland, but also in Germany and England. Later, Henry Nestlé established a condensed milk company at Vevey, on Lake Geneva. In 1904 the two companies were consolidated as the Nestlé and Anglo-Swiss Condensed Milk Company. In 1905 there were thirty-two Swiss condenseries. Several other condensed milk companies are operating in Switzerland, including the Schweitz, Milch-Gesellschaft at Hochdorf, the Berneralpen-Milch-Gesellschaft at Stalden, and Tobler at Bischoffszell.

From topographical necessity, Switzerland is a dairy country, little of her land being suitable for general agriculture, while the abundant growth of grass on the mountains supplies ideal provender for dairy cows. The Alpine dairies are known all over the world.

Switzerland, like most European countries, is obliged to import foodstuffs; the visitor is astonished to learn, after hearing the tinkling of cow-bells everywhere, that the butter served on

Courtesy of Molkerei, Zürich.

FIG. 12.—MILK PLANT, ZÜRICH.

Swiss exports of dairy products have decreased since the War, on account of the great increase of consumption of milk and milk products in Switzerland.

the table has come from Denmark, Italy, or Argentina. One may visit a dairy in Zürich or in some other Swiss city, and observe the working of butter in a churn, but one will probably be mistaken in supposing that it was made in the same churn.

Switzerland exports the well-known Emmenthal cheese, commonly known as Swiss cheese. The greater part of her milk production, aside from that consumed as raw milk, goes to the

cheese factories and condenseries. The ratio of dairy products to total agricultural exports is about as great as in the case of Denmark, being, for most years, as much as 80 to 90 per cent, if cattle be added to cheese, condensed milk, and infant foods.

From 1870 to 1875 the exports of condensed milk averaged nearly 9 million lbs. The total had increased to 25 million lbs. by 1884. The table shows the fluctuations since that time.

Swiss Imports and Exports of Condensed Milk

Year	Imports		Exports		Swiss Production of Condensed Milk, Millions of Pounds
	Thousands of Pounds	Value, Francs	Thousands of Pounds	Value, Francs	
Av. 1885–90	11	8,600	25,010	12,893,000	
Av. 1891–95	11	8,505	36,850	19,234,000	
Av. 1896–00	37	22,400	46,328	23,433,000	
Av. 1901–05	52	31,780	67,048	32,951,000	
Av. 1906–10	104	59,728	60,340	30,458,000	
1911	274	205,350	77,997	38,533,000	90
1912	203	162,720	83,442	47,099,000	90
1913	244	195,200	81,117	44,195,000	80
1914	287	230,080	90,784	47,419,000	110
1915	651	601,805	87,363	46,883,000	100
1916	67	84,600	79,549	57,296,000	90
1917	393	408,000	55,794	45,443,000	60
1918	4	8,486	40,143	43,006,000	50
1919	10,460	14,974,823	20,000	21,903,000	
1920	5,596	11,844,345	42,196	47,613,000	42
1921	1,299	....	42,479	....	60
1922	4	....	41,253	....	44

It will be observed that nearly all the condensed milk produced in Switzerland is exported.

France

With respect to dairy products, France is a consuming nation. She is noted for her cheeses, but her consumption is much greater than her production. This is true also of butter. Formerly, France exported more condensed milk than she imported, but

since the War this condition is reversed. A table of exports and imports follows.

French Imports and Exports of Condensed Milk and Milk Powder
(Thousands of Pounds)

	Condensed Milk					
	Unsweetened		Sweetened		Milk Powder	
	Imports	Exports	Imports	Exports	Imports	Exports
Pre-war Av.	613	1,313	1,789	2,810	774	83
1914	1,195	1,181	13,233	2,734	529	
1915	1,103	1,325	7,944	4,448	1,113	
1916	10,483	674	12,315	1,516	641	132
1917	57,637	501	21,881	344	929	82
1918	19,475	569	10,830	90	312	10
1919	58,540	766	35,493	1,155	1,419	63
1920	72,286	10,210	13,521	6,643	1,715	169
1921	21,472	7,345	12,330	3,290	2,409	87
1922	16,740	4,117	11,138	2,550	2,793	56

United Kingdom

England is the greatest market for condensed milk, but a part of her imported condensed milk is again exported. A small amount of condensed milk is manufactured in England. In 1921, out of 11,000 million lbs. of milk produced, 318 million lbs. were used for making condensed milk. In Ireland, whose milk production ranges from 5456 to 7274 million lbs., from 10 to 55 million lbs. are used for this purpose, as well as from 36 to 55 million lbs. of skimmed milk. A table of imports and exports follows.

Imports and Exports of Condensed Milk, Great Britain and Ireland
(Thousands of Pounds)

	Unsweetened			Sweetened		
	Imports	Exports	Reexports	Imports	Exports	Reexports
Pre-war Av.	5,808	1,868	1,344	108,609	41,877	3,141
1914	3,800	2,115	708	120,698	40,656	2,657
1915	28,200	566	2,401	132,081	33,570	2,791
1916	67,954	348	5,991	105,564	31,592	885
1917	62,939	1,048	2,220	103,325	11,899	467
1918	91,514	336	217	169,374	918	122
1919	104,996	267	34,445	218,031	1,036	1,207
1920	27,335	520	18,287	171,279	5,531	1,667
1921	62,277	1,379	5,518	158,938	2,309	2,193
1922	27,452	1,372	2,548	164,010	12,771	1,610

IMPORTS AND EXPORTS OF POWDERED MILK AND OTHER MILK CONSERVE

(Thousands of Pounds)

	Imports	Exports	Reexports
Pre-war Av.	3,858	19	275
1914	5,693	15	1,062
1915	8,514	1	2,382
1916	4,521	....	2,034
1917	6,515	....	618
1918	14,231	....	15
1919	17,107	3	1,171
1920	15,518	286	947
1921	17,624	971	2,742

NORWAY

While nearly 600 million lbs. of milk are annually produced in Norway, most of it is used within the country as fresh milk, butter, and cheese. Although dairying is one of the most important industries of the country, Norway imports butter and cheese since the War. Condensed milk imports and exports are shown in the following table.

NORWAY'S IMPORTS AND EXPORTS OF CONDENSED MILK

(Thousands of Pounds)

	Unsweetened			Sweetened		
	Imports	Exports	Reexports	Imports	Exports	Reexport
Pre-war Av.	1	5,339	...	1	27,787	
1914	1	6,170	...	1	22,642	
1915	6	5,185	...	1	17,585	
1916	16	371	...	1	15,757	
1917	......	1,223	...	6	14,484	
1918	2	.....	...	13		
1919	5,060	6	714	2,235	662	1,421
1920	3,264	491	2	90	8,360	31
1921	874	746	463	224	5,201	34
1922	652	2,557	...	102	11,459	

Sweden

Swedish Imports and Exports of Milk Conserves

(Thousands of Pounds)

	Imports	Exports
Pre-war Av.	25	84
1914	25	18
1915	46	382
1916	32	862
1917	84	447
1918	29	
1919	10,198	3,912
1920	1,989	881
1921	86	424
1922	150	

Czechoslovakia

Czechoslovakia produced 96,400 lbs. of condensed milk in 1920. She imported 4,076,800 lbs. in 1921 and 1,005,800 lbs. in 1922.

Germany

The following table shows pre-war figures for Germany, and such data on recent imports and exports as are available.

German Imports and Exports of Condensed Milk

(Thousands of Pounds)

Year	Imports	Exports	Year	Imports	Exports
1909	46	11,409	1920	9,181	525
1910	59	10,132	1921	6,689	2,890
1911	53	10,402	1922	9,294	1,022
1912	57	10,256	1923	8,872	582
1913	114	18,203			

CONDENSED MILK INDUSTRY IN THE SOUTHERN HEMISPHERE

The relative importance of agriculture tends to grow less in older countries. As land becomes too valuable for pasturing beef cattle, the meat industry is driven away to new countries. North America once controlled the world's markets for beef and wool. Now, Australian wool dominates the world market, and Australian and South American meats are distributed all over the world.

The development of agricultural industry moves, in general, from the extensive to the intensive. The raising of cattle on ranges was abandoned in old countries a long time ago. It was formerly practised in eastern North America, but as agricultural industry progressed it was driven westward and now remains only in the Rocky Mountain region. When Australian and Argentine colonization began, the range method of raising cattle was established in these new countries.

Shepherds were once seen everywhere in the old countries and were an attraction to artists and poets. Now they have only historical importance. Even in North America the sheep industry has to a great extent been driven into undeveloped sections of the continent. Still newer countries, such as Australia and other parts of the Southern Hemisphere, are now furnishing the main supplies of wool and mutton for the markets of the world. Dairying and swine husbandry tend to take the place of beef cattle and sheep industries and even of general farming.

The supremacy of Denmark, Holland, Switzerland, and Canada in the exportation of dairy products can no longer be maintained. This is not because their dairy industry is declining or unprofitable, but is due to other causes: first, population is increasing; and second, as civilization advances, the value of dairy products is more and more appreciated. These conditions tend to cause greater home consumption. At the same time, southern countries are realizing the profitableness of dairying and are competing with their northern sisters.

Industrial, climatic, and transportation conditions prevented any important movement across the equator until about forty years ago. On January 17, 1881, it is said, the steamship *Protos* landed in London 100 tons of butter from Australia in perfect condition. This successful venture opened the markets of the Northern Hemisphere to the dairy products of the Southern Hemisphere. With the aid of refrigeration, the southern countries have made great progress in the last decade in the exportation of dairy products.

New Zealand is now the largest exporter of cheese; and, if the rate of increase of recent years be maintained, she will soon be the largest exporter of butter also. The condensed milk and

milk-powder industries in New Zealand and Australia are of no small importance. Since the invasion of Australia by the Anglo-Swiss Company in 1909, great strides have been made in improving the industry in that part of the world. The production is increasing year by year, and the time when southern condensed milk will dominate the world market is not far away. The future of the condensed milk business in Argentina will probably be even greater than in Australasia. The Southern Hemisphere has vast areas adapted to dairying, which are as yet undeveloped. Authorities in New Zealand expect to see a 100 per cent increase in dairy exports in the next ten years. Further development is expected in some parts of Australia also, especially in Queensland. Many parts of South Africa offer good opportunities for dairying, and the Fiji Islands are also said to be a probable source of dairy products in the future.

The development of the dairy industry in general leads to the development of the business of condensing milk in various forms. As has been stated, New Zealand and Australia already have well-established condenseries, and it is more than likely that Argentina will soon follow their example.

Condensed Milk Transactions in Australia

(Thousands of Pounds)

From 1914 on, the year begins July 1 and extends to June 30 of the following year.

Year	Production	Imports	Exports	Reexports
1909	11,726			
1910	11,602			
1911	20,850			
1912	27,270			
1913	29,651	(pre-war av.) 4,085	1,068	173
1914	30,877	2,356	4,452	144
1915	24,473	3,802	642	210
1916	41,454	1,458	14,313	614
1917	50,972	701	22,844	462
1918	56,950	522	25,342	25
1919	60,200	976	32,248	18
1920	64,359	568	33,821	91
1921	52,386			
1923	51,510			

Australia has changed in the past few years from an importer to an exporter of condensed milk.

New Zealand

The position of New Zealand is next to that of the United States in the production of condensed milk, and the powdered milk industry is developing rapidly.

Milk Conserves in New Zealand

(Thousands of Pounds)

Year	Imports	Exports	Reexports	Production: Condensed Milk	Production: Powder
Pre-war Av.	237	117	105		
1914	880	44	218		
1915	749	1,066	356		
1916	278	893	175		
1917	527	3,723	75		
1918	658	6,406	135	703,931	3,364
1919	637	9,521	118	773,827	10,810
1920	738	12,655	126	554,485	12,802
1921	37	16,966			
1922	14	10,361			
1923	...	......	...	4,363	13,494
	...	. . .	...		

Argentina

Milk production in Argentina has risen from 498 million lbs. in 1909 to 2239 million lbs. in 1922, but the making of condensed milk had not been begun in 1924. Argentina imports condensed milk. One and one-half million pounds came in in 1919, and half as much in 1920.

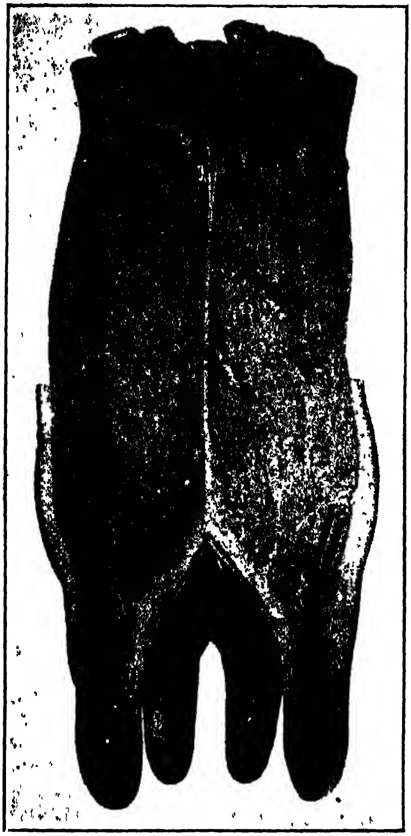
Chile

Milk production in Chile has been fairly constant for some years, at a figure slightly less than 300 million lbs. No condenseries are in operation as yet. The imports for ten years have averaged about 1 million lbs. of condensed milk.

CHAPTER II

MILK SUPPLY

Without an abundant supply of milk, no condensery can be run economically; and the quality of the milk is even more important than the quantity. The author's experience indicates that, in order to be operated profitably, a condensery should be so situated as to receive at least 10,000 lbs. of milk a day. With poor milk, even the most skillful dairy engineer cannot make the first-class product which alone commands the best price.



After Professor Dr. Otto Zietschmann, Zürich.

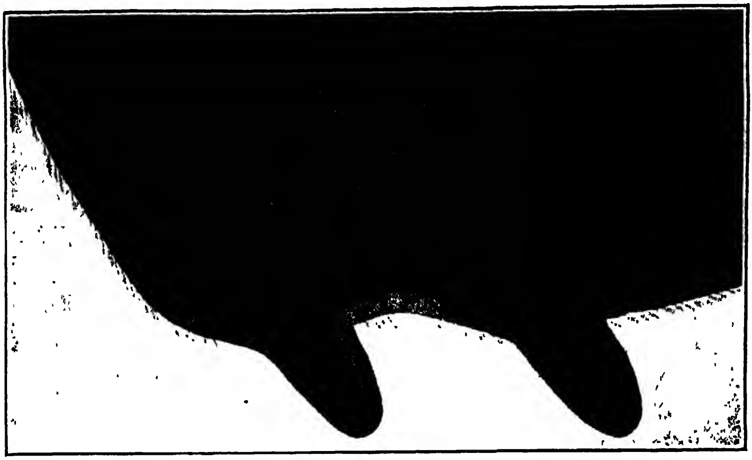
Fig. 13.—Structure of Cow's Udder. Cross Section from Left to Right.

The milk is secreted by milk glands imbedded in the tissues of the udder.

MILK

Milk is the secretion from the mammary glands of female mammals, produced after parturition; it contains in ideal proportions all the nutrients necessary for the growth of the young. Its composition varies with different species, with different breeds, and even with different individuals. In the case of the same individual, milk varies with the stage of lactation, with the season of the year, and with the time of milking. In general, it may be said that milk is a yellowish-white, opaque fluid having

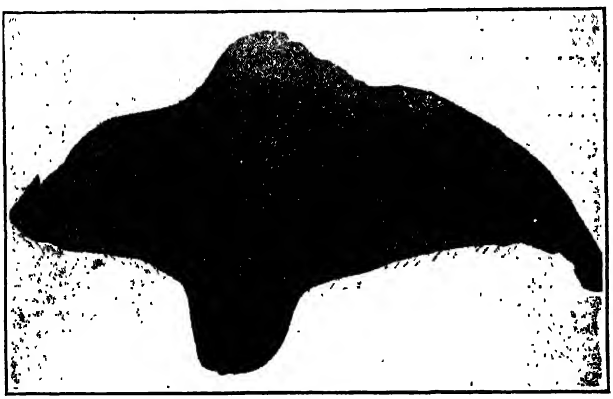
as its chief constituents fats, proteins, sugars, and salts, dissolved or suspended in water.



After Professor Dr. Otto Zietschmann, Zurich.

Fig. 14.—Structure of Cow's Udder. Cross Section Lengthwise. There is a milk cistern over each teat.

The fat of milk is in the form of microscopic globules suspended in the liquid. The proteins are mostly in the form of a



After Professor Dr. Otto Zietschmann, Zurich.

Fig. 15.—Cross Section of Mare's Udder through a Teat.

colloidal solution ("sol"), though some are in true solution. The salts are mostly in true solution, but a small part is suspended. The sugar is in a state of true solution.

The only kind of milk with which we are concerned in the making of condensed milk is that of the cow. Since cow's milk and condensed milk are often used as substitutes for other milk, it will be worth while to compare the different kinds of milk. As already stated, the composition of milk varies with individuals, and no accurate figures can be given for any species or for any breed. The following table gives an idea of the composition of the milk of different mammals.

Composition of Milk of Different Mammals, Percentages of Whole

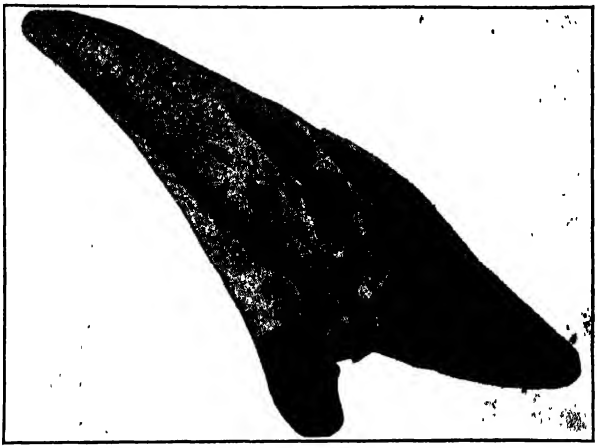
Species	Water	Protein	Fat	Sugar	Salts
Ass	90.0	2 1	1.3	6.3	0.3
Buffalo, China	76.9	6.0	12 1	3.7	0.9
" India	82.1	4.0	7 9	5.2	0.8
" Italy	82.2	4.1	8.0	4 7	1.0
" Philippines	82.2	5.0	6 9	5 2	0.8
Camel	?	?	3 1	5 6	1.8
Caribou	78 5	5 9	10 3	4.3	0.8
Cat	81.6	9 1	3 3	4 9	0 6
Cow	87.2	3 6	3 7	4.9	0.7
Dog	75.4	9.9	9 6	3.2	0.7
Dolphin	48.7	. .	43 8	...	0.5
Elephant	67.8	3 1	19 6	8 8	0.7
Ewe	83.5	5 7	6 1	4 0	0.7
Gamoose	84.1	3 9	5 6	5 4	1.0
Goat	86 9	3 7	4.1	4 4	0.9
Human	87.6	2.0	3 7	6 4	0.3
Llama	?	?	3 2	5 6	0.8
Mare	90.1	1 9	1 1	6.7	0 3
Pig	82.4	6.1	6.4	4.0	1.1
Porpoise	?	?	54 8	?	0.5
Rabbit	?	?	10 5	2.0	2.6
Reindeer	67.7	10.9	17 1	2.8	1.5
Whale	60.5	12.4	20 0	5.6	1.5
Zebu	86.1	3 0	4.8	5 3	0.7

In general, milk from an animal that gives a large volume of milk and whose young take long to mature is thin, that is, has a large water content. Ass's, cow's, mare's, and human milk are comparatively thin, while that of the dog, cat, ewe, and pig are rich. The latter group of animals give a small volume of milk and their young mature quickly. The milk of the elephant,

whale, and dolphin is extraordinarily rich. This is due to the fact that the feeding of so large a young animal requires more nutriment than could be provided in the form of a thin milk without making an inconveniently large volume.

Physical Properties of Cow's Milk

As is well known, cow's milk is a yellowish-white fluid. When fresh it shows an amphoteric character. The specific gravity usually varies between 1.029 and 1.033. An individual cow may give milk with as low a specific gravity as 1.0135, while the milk of another may reach 1.034. The average is about 1.0322.



After Professor Dr. Otto Zietschmann, Zürich.

Fig. 16.—Structure of Goat's Udder. Cross Section through a Teat.

The viscosity of milk, compared with water at 0° C., is 220 : 100; at 30° C. it is 170 : 100. The foaming of cold milk and cream and the difficulty of straining and separating cold milk are partly due to this higher viscosity. Cream is whipped cold in order that it may foam better on account of the higher viscosity.

The freezing point of cow's milk is lower than that of water, lying between −0.55° and −0.57° C. The addition of water to milk raises the freezing point. This fact is made use of as a means of detecting the adulteration of milk with water. According to J. Winter and E. Parmentier,[1] the freezing point of pure

[1] Exp. Sta. Record.

milk is rather constant, being about −0.555°. Milk is unlike water in that its temperature of greatest density is at its freezing point.

The boiling point of milk is about 0.2° C. higher than that of water. The specific heat of milk varies with its constituents. According to Fleischmann,[2] if the specific heat of water be taken as unity, that of milk is, on an average, 0.9457.

The refractive index of the acetic serum of normal cow's milk is lower than that of either goat's or sheep's milk, and lies between

Courtesy of the Central Association of Animal Industry in Japan.

FIG. 17.—HOLDER OF A GREAT MILK RECORD.

This cow has given more than 41,000 lbs. of milk in a year, containing more than 1800 lbs. of butter fat.

1.343 and 1.445. This variation is due to differences in water content, in soluble salts, and most of all in sugar.

The electrical resistance of cow's milk has been studied by many with a view to using this factor as a test of the quality of the milk. It varies greatly in different samples, and changes rapidly with change of temperature. According to F. Peterson,[3]

[2] Ver. d. bayer. Academie d. Wissensch.
[3] Untersuchungen über den electr. Widerstand der milch.

it varies from 186 to 304 ohms at 15° C., averaging 231.64 ohms. Mixed milk showed a variation of 204 to 255 ohms. The author's experiments showed a range of 178 to 235 ohms at 15° C. The wide variation with temperature is illustrated by the following examples. Sample 1: 227.5 ohms at 13.5° C.; 162 at 25°; 113.7 at 45°; 72.9 at 77°. Sample 2: 218.2 at 15°; 170 at 25°; 129.5 at 35°; 113.2 at 45°; 87.5 at 75°. Sample 3: 218.1 at 15°; 77.7 at 75°. Many other samples gave similar results. With increase in temperature, resistance decreases rapidly; or, to state this fact in terms of conductivity, with rise in temperature conductivity increases. According to J. H. Coste and E. T. Shelbourne,[4] the coefficient of electric conductivity is 0.000093 at 15° C.; they state that this quantity is 2.3 per cent of the total conductivity at that temperature. They give the range of conductivity of normal milk at 15° as from 0.0035 to 0.0045. Two hundred tests showed that one-half of all samples were between 0.0040 and 0.0042.

The formation of acid in milk causes a rise in conductivity, but this rise is not proportional to the amount of acid. When the acidity reaches a certain figure, the conductivity is said not to increase with further rise in acidity. It is also said that there is not much relation between the conductivity and the content of the milk in total solids and ash. The conductivity is affected, however, by the chlorine content of the milk ash. The addition of water to milk has little effect on the conductivity. This is explained by the dissociation of insoluble phosphates and citrates in added water.

Upon heating above 50° C., fresh milk does not show any visible change except the formation of a thin film on the surface, due to the rapid evaporation of water from the surface. The film is made up of casein and albumins, which coagulate at comparatively low temperatures, together with enclosed fat and other milk constituents. It has been supposed to consist of cream, but this is erroneous.

[4] Exp. Sta. Record, 1919.

Acidity of Milk

As already stated, fresh milk is amphoteric in character, but it always gives an acid reaction if phenolphthalein is used as indicator. According to Soxhlet and Henkel, 7 ml. of N/4 alkali are required to neutralize 100 ml. of fresh milk. This is equivalent to 0.1575 per cent acidity as usually expressed in America (i.e., in terms of the percentage of lactic acid). The author found that milk fresh from the cow showed from 0.13 to 0.22 per cent, averaging 0.17. It is not uncommon to find very fresh milk testing higher than 0.2 per cent, especially with rich milk such as Jersey and Guernsey. The acidity of colostrum is high, and that of strippings is low. The acidity of milk from a cow affected with mammitis is low on account of diminution of casein and carbonic acid. It is evident, therefore, that high acidity is not always an indication of poor quality in milk. In some milk-receiving plants, mistakes are made in grading milk by its acidity, and difficulties are experienced with milk producers. Provided milk is perfectly fresh, high acidity is an indication of high quality, and low acidity of poor quality. Acidity lower than 0.15 per cent indicates thin milk, or milk to which water has been added. Acidity lower than 0.13 per cent is an indication of strippings, of mammitis, or of milk neutralized with alkali. Such milk should be rejected. It usually has a bitter or salty taste. The following table on the acidity of fresh milk is from T. J. McInerney.[5]

Acidity and Solids of Fresh Jersey Milk

Cow No.	Acidity	Total Solids	Fat	Solids, not Fat	Ash
1	0.202	15 83	6.0	9.83	0.907
2	0.185	15 68	6.5	9.18	0.805
3	0.175	16 91	7.5	9.41	0.775
4	0 205	15.29	5 9	9.39	0.841
5	0 202	15.55	5.9	9.65	0.733
Herd Average	0.190	15.78	6 3	9.48	0.820

These figures confirm the statement made above that high acidity is often accompanied by high content of solids. The

[5] Jour. Dairy Sci., Vol. III, 1920.

following table from McInerney gives figures for various breeds.

ACIDITY OF MILK OF DIFFERENT BREEDS

Breed	Average	Highest	Lowest
Holstein	0.136	0.180	0.100
Jersey	0 162	0.220	0.130
Guernsey	0 139	0.160	0.120
Ayrshire	0.123	0.150	0.105
Shorthorn	0.180	0.200	0.165

McInerney states that there appears to be no relation between the period of lactation and the percentage of apparent acid in the milk. This is contrary to the author's findings. He found a definite relation between the stage of lactation and the apparent acidity of the milk. During the first part of lactation, the acidity is rather high. At the end of the first month it assumes the normal acidity for the individual. This normal acidity continues until about a month before the cow is due to go dry. From that time the acidity begins to diminish, and two or three weeks before drying it falls considerably. When milk falls much below its normal acidity, the cause should be sought. Unusually low acidity indicates, as stated above, either an abnormal condition or a too-advanced stage of lactation. In such a case the cow should be attended to and her milk should not be used.

This relation of degree of acidity to stage of lactation can be seen clearly only when the samples are taken and tested immediately after milking, at every milking throughout the whole period of lactation. Simply taking occasional samples will not serve to give a satisfactory view of the gradual changes, especially in the earlier and later periods.

McInerney also states that there is no apparent relation between the age of the cow and the percentage of apparent acid found in the milk, the acidity of milk being rather a matter of individual characteristics, as in the case of other milk constituents. He did not find any effect of feed on the acidity. It was formerly claimed by condenserymen that ensilage increased the acidity of milk and rendered it unfit for use in the manufacture of condensed milk. This criticism is without foundation. When cows are in the best physiological condition to secrete milk, the

apparent acidity is relatively high. Succulent feeds, including, of course, ensilage, have the effect of bringing the cows into better condition and so stimulating milk secretion and raising the apparent acidity. This does not mean, however, that there is any increase in actual free acid. Phenolphthalein reacts to many salts, and the apparent acidity of milk is due in part to such constituents. Changes in apparent acidity may therefore result from molecular rearrangements among the mineral constituents and have no relation to actual free acid.

McInerney again states that fresh milk comparatively low in solids-not-fat and in ash showed a lower percentage of apparent acidity. Generally speaking, this is true. As before stated, rich milk is often high in apparent acidity. This is largely due to the high casein content of rich milk, and, in turn, casein is largely responsible for the apparent acidity of fresh milk. As to the effect of low ash, the case is different. Such a salt as sodium acid phosphate, which is believed to be present in milk, would account for the acid reaction of milk with phenolphthalein. But some alkaline salts seem to lower the acidity. Milk in an advanced stage of lactation has an increased ash content and a reduced acidity. The bitter and salty taste of such milk is due to increased ash content. The low acidity of mammitis milk is due, as stated before, to decrease in casein and increase in alkaline salts. As to the bitter milk of advanced lactation, however, Leroy Palmer states that it is caused by the secretion of an active lipase in the milk, which hydrolyzes the milk fat quite rapidly, even at fairly low temperatures, with the liberation of fatty acids. Among these are the lower volatile fatty acids, especially butyric, which imparts in large measure the bitter flavor and rancid odor to the milk. Palmer also states that this difficulty can be effectively reduced by heating fresh milk to 75° C. for a few minutes.

As to the value of the titration test, at factories, R. S. Fleming and J. T. Nair [6] state that the normal acidity of fresh milk from individual cows is from 0.140 to 0.145 per cent; that the normal acidity of composite milk received at the factory is 0.140 per cent; and that where milk is handled in a cleanly and careful manner it will not be rejected on the basis of any acid tests now in use

[6] Jour. Dairy Sci., Vol. IV, 1921.

by the manufacturers of milk products. They state further that the value of the acid test in checking methods of production has been clearly demonstrated, and that its ease of application, combined with demonstrated reliability, warrants its use until such time as some other equally rapid and more dependable method of determining the quality of milk shall have been perfected. Granted that the acid test occasionally detects milks that naturally have a higher acidity than the standard, it must be admitted that such milk is abnormal and comes from abnormal cows. While Fleming and Nair admit the unreliability of the acid test in judging the quality of milk, still they strongly recommend its use, and go on to say:

> That the quality of this milk may not be poorer does not enter into the question. Such milk is abnormal, and no practical working scheme can allow for all abnormalities. The percentage of cows and herds showing abnormally high acid is so small as to be negligible and the manufacturer is doing no injustice to the producer when he insists that all milk must be delivered with an acidity below 0.17 or 0.18 per cent, particularly when such a test is applied as an adjunct to the nose and palate of the experimental inspector.

Fleming and Nair's argument must be appreciated. The acidity test must be used only as an auxiliary guide, and should not be the deciding factor. In judging the quality of milk in factories it is better to supplement this test with the alcohol test, and, of course, with the senses of smell and taste.

Coagulation of Milk

The coagulation of milk is, in general, caused by acid developed in the milk by the growth of bacteria. The degree of coagulation depends on the amount of acid developed. When acidity reaches 0.5 per cent, milk will coagulate at ordinary room temperature. If more than 0.05 per cent of lactic acid is present, milk will coagulate on heating, the temperature depending on the degree of acid development. Heat coagulation of milk is most objectionable in the manufacture of condensed milk.

The relation between the coagulation temperature and the

degree of acidity was studied by T. J. McInerney.[7] In the conclusion to his preliminary report he says:

> These experiments show that milk containing 0.57 per cent acid (in terms of lactic acid) will, on the average, precipitate at a temperature between 60° and 65° F. (15.5° and 18.3° C.). Milk containing 0.50 per cent acid will coagulate at 75° to 80° F. (23.9° to 26.7° C.); 0.40 per cent, at 100° to 110° F. (37.8° to 40.6° C.); 0.35 per cent, at about 150° F. (65.6° C.); and 0.25 per cent will not cause coagulation until heated to 180° F. (82.2° C.).

The small drop in acidity between 0.40 and 0.35 per cent, corresponds to a great difference in coagulation temperature. To quote again from McInerney:

> The author believes that, when the milk is heated to about 100° F., a chemical change may take place in the calcium salts found in milk, and in some way cause the casein to be held in suspension. The addition of disodium phosphate will retard the precipitation of the curd in milk even though a high percentage of lactic acid is present. A sample of milk showing 0.60 per cent acid curdled when heated to 60° F. (15.5° C.). Another 18-gram sample of the same milk to which was added 20 cc. of a 1 per cent solution of disodium phosphate (Na_2HPO_4) did not coagulate when heated to 175° F. (79.4° C.).
>
> The addition of monocalcium phosphate ($CaH_4P_2O_8$) has an entirely different effect from the sodium phosphate. * * * To 20 cc. of skimmed milk containing 0.18 per cent acid were added 44 cc. of a 1 per cent solution of monocalcium phosphate, and the sample curdled at 70° F.

From these experiments, McInerney believes that the phosphates in the milk are concerned in the relation of temperature to acidity in coagulation.

H. H. Sommer and E. B. Hart [8] found that in fresh milk there is no relation between the titratable acidity and the heat coagulation, the main factor of which they found to be the salt composition of the milk, especially the calcium, magnesium, citrate, and phosphate content. The effect of the calcium and magnesium salts is opposed to that of the citrate and phosphate content. An excess of either of these two classes of salts causes the milk

[7] Jour. Dairy Sci., Vol. III, 1920.

[8] Jour. Dairy Sci., Vol. V, 1922.

to coagulate more readily. In a number of cases Sommer and Hart succeeded in remedying the troublesome coagulation of evaporated milk on a commercial scale by the addition of the proper amount of sodium citrate or disodium phosphate. This accords well with the findings of McInerney. L. A. Rogers, E. F. Deysher and F. R. Evans,[9] however, could not find any definite relation between the acid-base ratio of the raw milk and the coagulation point of the evaporated milk, under commercial conditions.

Fresh milk will coagulate without the development of free acid when it is subjected to a high temperature, the degree varying with individuals. This fact has a practical bearing on the manufacture of condensed milk, particularly evaporated milk. According to Rogers and his co-workers, there is no definite relation between the coagulation temperature of raw milk and that of the same milk after evaporation. Their data are as follows:

Coagulation Temperature of Milk before and after Evaporation

(Twenty Minutes' Exposure)

Raw		Evaporated		Raw		Evaporated	
°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.
137	278.6	128	262.4	140	284.0	107	224.6
134	273.2	125	257.0	140	284.0	105	221.0
136	276.8	112	233.6	141	285.8	130	266.0
137	278.6	115	239.0	142	287.6	133	271.4
137	278.6	131	267.8	143	289.4	122	251.6
140	284.0	119	246.2	143	289.4	125	257.0
140	284.0	113	235.4	146	294.8	113	235.4

Sour milk coagulates readily with alcohol. Applying this principle, the alcohol test is sometimes used to grade milk. The test is usually made by mixing with the sample of milk an equal volume of alcohol whose strength is 68 or 70 per cent by volume. It is a very simple and practical test, but, like many other methods for grading milk, it is not perfect. It is frequently found that perfectly fresh milk coagulates with alcohol. H. H. Sommer

[9] Jour. Dairy Sci., Vol. IV, 1921.

and T. H. Binney [10] investigated the factors that influence the coagulation of milk in the alcohol test. They say that the various causes given by many authors for the coagulation of fresh milk in alcohol are rather indirect and only operative in so far as they affect the chemical composition and properties of the milk. They found that the nature of the salts in the milk has much to do with this coagulation.

Milk, as stated before, is a mixture of colloids and electrolytes. It is a well-known fact that electrolytes have a marked effect on the stability of colloidal solutions ("sols"), especially those that yield doubly and triply charged ions on dissociation. As we have milk salts containing, as will be shown later, appreciable amounts of bivalent calcium and magnesium and of trivalent phosphate and citrate in a colloidal solution of albumin and casein, the stability of milk proteids must be influenced by the amount of these salts present in the milk. The effect of milk salts on the coagulation of milk with rennet was shown long ago. The effect of calcium and magnesium and of phosphates and citrates on heat coagulation has been demonstrated by Sommer and Hart. In order to determine experimentally what effect the various milk salts have on the alcohol test, Sommer and Hart made the following experiment.

Fourth-molar solutions of calcium acetate, magnesium chloride, potassium chloride, dipotassium phosphate, and sodium citrate were prepared and added to 25 cc. of fresh milk, in a series differing by 0.1 cc. of salt solution. In each series the dilution was equalized by the addition of the proper amount of distilled water. The addition of 0.1 cc. of M/4 magnesium chloride or 0.2 cc. of calcium acetate to 25 cc. of fresh milk was sufficient to cause a positive reaction with the alcohol test. These additions are equivalent to an increase of 0.0112 and 0.004 per cent CaO and MgO, respectively. As much as 0.9 cc. of M/4 potassium chloride, dipotassium phosphate, and sodium citrate, added to 25 cc. of fresh milk, failed to give a positive alcohol test. The strength of the alcohol used was 70 or 75 per cent by volume.

Sommer and Hart showed that an increase of 0.0112 per cent in the CaO content changed a negative sample to a positive one.

[10] Proc. World's Dairy Congress, 1923.

Such differences in calcium content of milk are often found. The same authors, in analyzing thirty samples of milk, found the CaO content varying from 0.132 to 0.210 per cent.

Sommer and his co-worker experimented on the relation of acidity to the alcohol test, with the following results: Normal milk became positive to the alcohol test when the acidity had reached 0.25 per cent. The milk to which calcium acetate had been added became positive at 0.20 per cent, while that to which potassium phosphate had been added did not become positive until the acidity had reached 0.30 per cent. The effects of acidity and of salts on the alcohol test were additive, 0.007 per cent CaO being equivalent to an increase in acidity of 0.06 per cent, and 0.0088 per cent P_2O_5 being equivalent to a decrease in acidity of 0.04 per cent.

The effect of rennet enzyme on the alcohol test was studied by the same authors. It was found that prepared rennet caused a positive reaction in the alcohol test, the amount of effect depending on the amount of rennet and the time during which it was allowed to act. The coagulating enzymes produced by 856,000 rennet-forming organisms per cubic centimeter caused a positive alcohol test. However, it is stated that the rennet-forming organisms must be regarded as a minor factor in the alcohol test, for their prevalence in milk rarely approaches this figure.

Hydrogen-ion Concentration of Milk

The fact that the combining power of an acid solution depends on its hydrogen-ion concentration is well known among chemists, and it is customary to express this effective acidity in terms of the "*p*H value," measured with a special type of potentiometer. Apparent acidity simply expresses the amount of alkali required to make the milk neutral to phenolphthalein, and is quite different from actual effective acid. Mistakes in judging the quality of milk by the titration method are often traceable to this difference.

In common with many other properties of fresh milk, the hydrogen-ion concentration varies. The *p*H values are commonly between 6.7 and 6.9. The figure for pure boiled distilled water is close to 6.9, and lower values correspond to higher

actual acidity, that is, higher hydrogen-ion concentration. As acid forms in milk, the pH value falls, as would be expected; but there is no definite relation at any stage between the apparent acidity and the pH value. L. A. Rogers [11] and his co-worker, in their study of the relation of acidity to the coagulation temperature of evaporated milk, say that, notwithstanding the generally accepted views as to the usefulness of grading milk on the basis of titratable acidity, the results obtained by determining the hydrogen-ion concentration electrometrically do not indicate that the relation between the acidity of the fresh milk and the coagulating point after evaporation is sufficiently uniform to be of much value in grading milk. This is evident, they further say, because the hydrogen-ion concentration that gives maximum stability to the casein varies with the composition of the milk. The results show that any increase in the pH value of milk, above its normal figure, causes a distinct reduction in the coagulation temperature after evaporation, although the final hydrogen-ion concentration may still be considerably less than that of another sample which is comparatively stable. For this reason it would be difficult, if not impossible, to set any definite limit in hydrogen-ion concentration above which milk would be unsuitable for evaporating. The essential fact which must be established is not the actual value found for the pH, but, as in the case of the titratable acidity, whether the figure has changed from the normal for that particular milk.

The relation between the hydrogen-ion concentration and the bacterial content of commercial milk was studied by Edwin W. Schultz, Alberta Marx, and Harold J. Beaver.[12] They report that the results thus far obtained do not permit the drawing of definite conclusions. It is suggestive, they say, that at a pH value of 6.6, the count begins to run high, averaging 16 million, at 6.5 reaching an average of 100 million, etc., though at these values the acidity cannot be detected by the taste. At about pH 6.0 the acidity is first noticeable to the taste.

[11] Jour. Dairy Sci., Vol. V, 1922.
[12] Jour. Dairy Sci., Vol. V, 1922.

COLOSTRUM

Soon after parturition the cow secretes a deep-yellow or reddish-yellow, viscous milk, called colostrum. It is also called first milking, or beastings. Its appearance and properties vary considerably with the health of the cow, the deviation from the normal time of calving, and many other factors. In general, it has a somewhat tart taste. When allowed to stand, it soon separates into two layers, the upper one being very dense and yellow, and the lower a grayish-white, opaque liquid. The upper layer is much thicker than the cream of normal milk. The specific gravity is usually between 1.046 and 1.079. The author has observed extremes of 1.0365 and 1.0936. When heated, colostrum coagulates in much the same way as an egg. If acetic acid, mercuric chloride, or alcohol be added, it coagulates like normal milk, but with rennet it does not coagulate so readily or so perfectly as normal milk. Examined under the microscope, it shows many colostrum cells (*corps granuleux*). Some say that these are a product of the decomposition of epithelial cells, while others regard them as leucocytes enlarged by absorption of fat globules.

The composition of colostrum varies even more than that of normal milk. In all cases it has more solids than normal milk. According to Eugling, the colostrum of cow's milk has the following range in composition:

Composition of Cow's Colostrum

(Eugling)*

	Limits	Average
Water	76 60–67.43	71.69
Fat	1 88– 4.68	3.37
Casein	2 64– 7 14	4 83
Albumin	11 18–20 21	15 45
Sugar	1.34– 3 83	2.46
Ash	1.78– 1.18	1.23

* Monvoisin, Le Lait.

Monvoisin gives the amount of various constituents, in grams per liter, of cow's colostrum before and after calving.

AMOUNT OF VARIOUS CONSTITUENTS OF COLOSTRUM, GRAMS PER LITER

(Monvoisin)

	Four Days Before Calving	Twelve Hours After Calving
Acid	2.8	2.5
Dry matter	180.2	160 45
Fatty matter	17.0	46.1
Albuminoids	130.8	69.6
Lactose	19.5	33.1
Ash	9 8	9.1
Reductase	11 minutes	6 minutes

The test for reductase was made by the usual methylene blue decolorization method.

Vaudin[13] gives the following figures on the composition of colostrum:

PERCENTAGE COMPOSITION OF COLOSTRUM

(Vaudin)

	Solids	Ash	Lactose	Fat	Albuminoids
Night before calving	27.61	1.08	1.52	1.30	23.70
Immediately after calving	22 47 to 27.35	0 98 to 1 29	1.02 to 2 86	1.36 to 6.32	9.02 to 20 10
Five days later	14.37	0.77	4.07	5.18	4.35

Orla-Jensen [14] tried the effect on a Simmenthal cow of feeding herbage and cuttle fish with hay. The differences found in the colostrum may be due to the feeding or to other causes, because colostrum is very variable even for the same cow.

The figures already given show that colostrum changes rapidly as the lactation period advances. Bonn [13] made an experiment

[13] Monvoisin, Le Lait.
[14] Landwirts. Jahrbuch der Schweiz, 1905.
[13] Monvoisin, Le Lait.

with a cow six years old, fed on brewers' grain, bran, mangels, and linseed-oil cake. His results are given in the following table.

CHANGE OF COLOSTRUM TO NORMAL MILK

(A. Bonn)

	Density	Solids	Ash	Lactose	Fat	Protein
Morning after calving.	1.0500	19.20	0.80	2.64	1.20	15.16
1 day after calving.	1.0450	13.50	0.68	3.30	1.35	8.17
2 days " "	1.0333	12.30	0.75	3.71	2.00	5.84
3 " " "	1.0322	12.10	0.70	3.43	2.60	5.37
4 " " "	1.0320	11.65	0.70	3.62	2.40	4.93
5 " " "	1.0330	11.89	0.71	3.40	2.80	4.98
6 " " "	1.0318	11.71	0.68	3.62	2.90	4.51
7 " " "	1.0304	12.19	0.72	3.60	3.60	4.27
8 " " "	1.0316	12.49	0.70	4.56	3.60	3.63
9 " " "	1.0312	12.51	0 70	4.77	3.70	3.34
10 " " "	1.0306	11.89	0.68	4.56	3.30	3.35
11 " " "	1.0302	11.67	0 68	4.56	3.20	3.23
12 " " "	1.0312	11.64	0.65	4.77	3.00	3.22
13 " " "	1 0302	11.94	0.67	5.81	2.80	2.66
14 " " "	1.0304	11.72	0.65	4.77	3.10	3.20

The composition becomes normal after seven days. The high density of colostrum is due to high total solids with low fat content. A high content of protein is characteristic of colostrum, and the heat coagulation is due to this fact. As Eugling's analysis has shown, the protein content of colostrum consists largely of albumin, while in normal milk the protein content is largely casein, a protein which is peculiar to milk. Usually the fat content of colostrum is low and gradually increases. Sometimes it has a high fat content at the beginning. The ash is always high at first. The tart taste may be partly accounted for by the high ash content.

According to Monvoisin, the proportions of casein, albumin, and amide in the protein of colostrum changes very rapidly. The table on page 44 gives his results.

NITROGEN CONTENTS OF COLOSTRUM

(A. Monvoisin)

Day	Total Nitrogen Grams per Liter	Nitrogen of Casein		Nitrogen of Albumin		Nitrogen of Amides	
		Grams per Liter	Per Cent of Total N	Grams per Liter	Per Cent of Total N	Grams per Liter	Per Cent of Total N
(1) Calving eve . .	32 10	4 65	14 55	26.20	81.55	1 25	3.90
(2) Day of calving	28 40	2 10	7 40	24 55	86.45	1.75	6.15
(3) Second day after.	11 76	4 70	39 95	6.43	54 67	0.63	5.38
(4) Third day after.	7 10	4 13	58.10	2.39	33 70	0 58	8 20
(5) Fourth day after.	7 62	5 39	70 70	1 73	22 70	0.50	6 60
(6) Fifth day after.	7 56	5 04	66 60	2.03	27.00	0 49	6 40
(7) Sixth day after	6.92	5 08	73 40	1.29	18 65	0.55	7 95

The ash of colostrum is higher than that of normal milk. The analysis of the ash is as follows (subject to variation):

ASH OF COLOSTRUM, PERCENTAGES OF TOTAL ASH

Potash	7.23
Soda	5 72
Lime	34 85
Magnesia	2 06
Ferric oxide	0 52
Phosphoric anhydride	41 43
Sulphuric anhydride	0 16
Chlorine	11 15
Total	103 22
Less oxygen equivalent to chlorine	3 22
	100.00

Haudet [15] gives the change in colostrum with special reference to calcium phosphate as follows:

[15] Monvoisin, Le Lait.

ANALYSES OF COLOSTRUM ON CONSECUTIVE DAYS: PERCENTAGES ON WHOLE MILK (Haudet)

	Fat	Lactose	Soluble Proteids	Colloidal Proteids	Calcium Phosphate	Other Salts
Immediately after calving.	5.69	3.30	0.51	14.05	0.51	0.54
1 day after calving	4 48	4.05	0.93	5.21	0.43	0.43
2 days " "	5 70	4 32	1.98	3 52	0.43	0.45
3 " " "	7 40	4.26	2 41	3.45	0.43	0.40
4 " " "	3.20	4 44	0.56	5.20	0.40	0.30
6 " " "	4 20	4 64	1 19	4.02	0.38	0.29
8 " " "	4 10	4 96	0.48	3 56	0.40	0.30
14 " " "	3.85	5.05	0.58	3.74	0.35	0.36

The content of calcium phosphate is almost equal to that of all the other salts combined.

NORMAL MILK

Many average analyses of cow's milk are on record, but no two are alike in all respects. Even the milk of a single cow is not constant in composition. The breed has much to do with the analysis of milk; the individual, perhaps more. The season of the year and stage of lactation have no small importance, to say nothing of the time and manner of milking, etc. Average analyses from different sources are given in the table that follows.

COMPOSITION OF NORMAL MILK

	Water	Fat	Casein	Albumin	Lactose	Ash
280,000 analyses, London, Richmond *. . .	87 35	3 74	3.00	0 40	4.70	0.75
5,552 analyses, U. S. A., Van Slyke †	87 10	3.90	2 50	0 70	5.10	0.70
Cheese factory milk, N. Y., May to Nov., Van Slyke.	87 40	3 75	2.45	0 70	5.00	0.70
800 analyses, Germany, König ‡.	87.27	3 62	3.02	0 53	4.88	0.71
Average	87 29	3.76	2 74	0.58	4.92	0.71

* Richmond, Dairy Chemistry. † Van Slyke, Science and Practice of Cheese Making.
‡ Unters. Landw. u. Gewer. Wich. Stoff.

The influence of the breed of cattle on the composition of milk is often referred to. The data of the following table were compiled from the report of the Massachusetts State Board of Health, and from New York and New Jersey State Agricultural Experiment Stations.

COMPOSITION OF MILK BY BREEDS

	Fat	Lactose	Protein	Ash	Total
Jersey	5 65	4.94	3.46	0 72	14.77
Guernsey	5 23	4.84	3 73	0 75	14.55
Devon	4 15	5 07	3 76	0.76	13.74
Grade Jersey	4 65	4 87	3 45	0 75	13.72
Grade Guernsey	4 23	4 94	3 27	0 72	13.16
Grade Durham	4 29	4 86	3 39	0 73	13 27
Grade Ayrshire	4 22	4 85	3 22	0 75	13 04
Ayrshire	4 01	4 88	2 99	0 76	12 64
American Holderness	3 55	5 01	3 39	0 70	12 65
Grade Holstein	3 95	4 65	3 25	0 73	12 58
Shorthorn	3 65	4 80	3 27	0 73	12 45
Dutch Belted	3 56	4 93	2 96	0 70	12.15
Holstein	3 41	4 70	2 93	0 74	11.78

It will be noted from this table that, almost without exception, the breed whose milk is higher in total solids also gives a higher percentage of fat. The popular notion that Jersey and Guernsey milk is especially poor after skimming is not sustained by the facts. It will be noted that Devon and Holderness milk is especially rich in sugar. If these figures are compared with the general average in the previous table, it will be observed that Holstein milk falls below the average in every item. Shorthorn comes nearest to the average. The popularity of the Holstein breed among our dairymen tends to lower the average quality of milk produced. There is no question that the Holstein breed is one of the best of dairy cattle, and is a very profitable producer; but from the standpoint of improving the quality of market milk, an exclusive use of Holsteins is very questionable. In total solids, Jersey and Guernsey milk contains 25 per cent more than Holstein, and in fat, nearly 60 per cent.

The composition of normal milk is also modified by the stage

of lactation. Orla-Jensen [16] gives the results of analysis of Simmenthal milk at different stages. A table follows.

COMPOSITION OF SIMMENTHAL MILK AT DIFFERENT STAGES OF LACTATION

(Orla-Jensen)

	Density	Solids	Ash	Lactose	Fat	Albuminoids
1 month after calving.	1.0318	12 44	0 69	5.05	3.70	2.98
2 months " "	1.0326	12 64	0.71	5.18	3.70	3.04
3 " " "	1.0323	12.48	0 70	4.99	3 50	3.01
4 " " "	1.0321	13 02	0 69	5 01	3 97	3.35
5 " " "	1 0330	13 65	0 70	5 16	4 25	3 59
6 " " "	1 0329	13 72	0 73	5 13	4 47	3 63
7 " " "	1 0335	14 37	0 73	5 02	4 89	3 83
8 " " "	1 0342	14 03	0 74	4.82	4.70	4.08
9 " " "	1.0341	14.50	0.74	4.94	4.62	4 14

As lactation advances, the total solids increase, this increase being due to an increase in all solids except sugar. Another table follows, in which the lactation period was divided into fourteen parts of four weeks each.

INFLUENCE OF STAGE OF LACTATION ON COMPOSITION

Period	Total	Fat	Proteids	Lactose
1	12 74	4.00	2.68	4.87
2	12.26	3.85	2 36	4.84
3	12.29	3 79	2.49	4 94
4	12.24	3 77	2.49	4.82
5	12 35	3.82	2.62	4 80
6	12.50	3.79	2 68	4 75
7	12.61	3.83	2 68	4 88
8	12 70	3 85	2 74	4.83
9	12 78	3 97	2 87	4.62
10	13.16	4.11	3.06	4.55
11	13.46	4 22	3.19	4.74
12	14.04	4 54	3.38	4.91
13	14.23	4.66	3.64	4.70
14	15.29	5.08	3.70	5.01

[16] Landwirts. Jahrbuch der Schweitz, 1905.

The increase in total solids amounts to about 20 per cent of the amount present at the beginning; the increase in proteids to about 40 per cent; and the increase in fat which takes place irregularly to about 27 per cent.

A good milking cow will sometimes continue to give milk for years if she is not bred. The author had experience with a Jersey cow which became sterile and continued to give milk for five years, when she was sold to the butcher. In such a case the milk becomes less in quantity and richer in fat. Orla-Jensen made analyses of milk from a Simmenthal cow which was giving about 6 quarts of milk after nineteen months of lactation, and about 4 quarts in the twenty-ninth month.

COMPOSITION OF MILK OF PROLONGED LACTATION

(Orla-Jensen)

After Calving	Density	Solids	Ash	Lactose	Fat	Albuminoids
19 months... .	1.0325	15 84	0 79	4 39	6 10	4.45
26 "	1.0329	16 09	0.80	4 77	6 40	3 71
29 "	1 0341	16 46	0.84	4 38	6.46	4.41

Spaying a cow that is already giving milk prolongs the lactation in much the same way as when the cow becomes barren naturally. The effect of spaying on the composition of milk was studied by Dieulafait.

EFFECT OF SPAYING ON THE COMPOSITION OF MILK

	Total Solids	Ash	Lactose	Fat	Albuminoids
Before spaying........	12 35	0 75	4 17	3 13	4 50
After spaying	13 07	0.74	4.49	4.05	3.79

This would make it appear that the effect of spaying is to increase the fat content. Such a conclusion is hardly warranted, however, for any disturbance in the cow's anatomy is likely to influence the fat content of her milk, and the following figures from Lajoux show that the effect of spaying is just as likely to decrease as to increase the fat production.

LAJOUX'S ANALYSES OF MILK FROM SPAYED COWS

Cow 7 Yrs. Old. Last Calving May. Spayed June 9	Density	Solids	Ash	Lactose	Fat	Albuminoids
June 8	1.0308	14.39	0.66	4.79	5.48	3.45
June 9	......	13.59	0.68	4.562	4.28	4.068
July 7	......	14.01	0.73	5.041	4.79	3.459
Oct. 6	1 0328	13.56	0.72	5.064	4.52	3.261
Holstein Cow 11 Yrs. Old Last Calving April 30. Spayed June 18.						
June 17	..	11 37	0.63	4.438	2.73	3.572
June 19	1.0318	11 67	0.74	4 448	2.90	3.582
Oct. 13	......	11 61	0.73	4.197	2.87	3.183
Heifer, Calved May 6. Spayed Sept. 23.						
Sept. 22, night	1.0321	13 60	0.74	4.185	3 97	4.075
Sept. 23, morning	1.0321	12 16	0 74	4.562	2.42	4.438
Nov. 26	1.0347	13 40	0.74	4 357	4 49	3.813
Dec. 19	......	13 60	0 69	4 262	4 27	4 378

Unless a cow is bred, she comes in heat about once in three weeks. While she is in heat her physiological condition is much disturbed, and this may have some influence on the composition of her milk. This problem has been studied by many investigators, especially as to the fat content. There is usually, but not always, a decrease in fat content. The results are not consistent enough to be worth detailed study.

Time of milking also has an effect on the composition of milk. Morning and evening milkings, if the periods are equal, are not different in any consistent way. But if cows are milked three times a day, the noon milking is higher in fat than the other two. A table showing results of two such cases, after Fery, follows.

EFFECT OF TIME OF MILKING ON COMPOSITION OF MILK

	Density	Solids	Ash	Lactose	Fat	Albuminoids
Morning		11 44	0 66	5.21	2.50	2.72
Noon		13 53	0.57	5.32	4.72	2.72
Evening		12 62	0 65	5.22	3.63	2.96
Morning	1 0302	13 90	0 73	4.60	3.91	
Noon	1.0292	14.90	0 74	4.45	5.45	
Evening	1.0310	13.29	0.71	4.31	3.55	

In some parts of the world milking cows are used as beasts of burden, and the effect of work on the composition of the milk has been studied. It has been found that light work has a tendency to increase fat production slightly. Whether this would continue if the work were continued is a question. Exercise is good for the health of the cow, and light work may result in improved quality of milk.

Each quarter of the cow's udder may produce milk different from that of each other quarter. Sharpless and Lajoux [17] made a study of this point, finding notable differences. A table follows.

COMPOSITION OF MILK FROM DIFFERENT QUARTERS OF UDDER

After Sharpless	Density	Solids	Ash	Lactose	Fat	Albuminoids
Anterior, right ...	1 0250	14.84	0.68	4.09	5.59	4 48
left. ...	1.0240	13.80	0 61	2.18	4.43	6.58
Posterior, right...	1 0260	13 49	0.66	3 44	4.39	5.00
left ..	1 0280	14.30	0.67	4.20	3.84	5.59
After Lajoux						
Anterior, right		10.21	0.68	4 29	1.68	3 61
left....		9 64	0 66	4 33	1.28	3 37
Posterior, right...		10 48	0 56	4 91	1 31	3.70
left		10.25	0 57	5 34	0.79	3.55

The composition of milk also varies with the portion of the milking considered, the first part being thin and poor, and the latter part sometimes almost as rich as cream. Differences in fat content will be studied later. The following tables show differences in all constituents.

COMPOSITION OF MILK FROM DIFFERENT PORTIONS OF MILKING *

After Lajoux	Density	Solids	Ash	Lactose	Fat	Albuminoids
First portion....		10.00	0 51	5 13	1.19	3 17
Middle portion...		11.65	0.56	5.34	2.13	3.62
End portion....		13.31	0.53	5.13	4.31	3.34
After Malpeaux						
Beginning	1.0345	10.62	0 72	5 15	1.26	3.43
End............	1.0280	15.84	0.70	4.82	6.95	3.42

After Forster	Solids	Total N	Lactose	Fat	Salts
First portion	10 71	0 16	5.65	2.70	0.26
Middle portion....	11.95	0 14	5.95	3.89	0.26
Last portion.....	13 92	0 15	5 47	6.16	0.24

* Monvoisin, Le Lait.

[17] Monvoisin, Le Lait.

The chief variation is in the fat content. Other constituents are higher in the middle portion of the milking.

The influence of feeding on the composition of milk is the problem that has caused most discussion and dispute. It is now generally accepted that if cows are properly fed the kind of feed does not have any permanent influence on the composition of the milk. It is true that, by changing the mode of feeding, the composition of milk, especially the fat percentage, may be changed temporarily. Advantage is often taken of this fact in feeding cows for advanced registry, to get a higher percentage of fat. Only a rather small proportion of cows will respond to such treatment; to do so a cow must have a highly developed temperament and a great milking capacity. She must also be in good flesh. Such a cow is very sensitive and responds easily to any change of environment. A change of feed also affects the cow's physiological condition and so in turn affects the composition of the milk. When, however, the cow becomes used to the new feed, the composition of her milk goes back to normal. It may be considered that the temporary change in composition is an abnormality, due to the physiological condition of the cow, and it is not true that the kind of feed can change the composition of the milk.

When a cow is suffering from malnutrition she cannot produce normal milk. Under such conditions she takes most of the energy-supplying material in the feed for the maintenance of her body and leaves little for the production of milk. In such a case there is usually a decrease in milk solids, especially fat. Comparisons of milk secreted under conditions of malnutrition and high nutrition are given in the next table.

Influence of State of Nutrition on the Composition of Milk

(After F. Simon)*

	Solids	Albuminoids	Fat	Lactose	Salts
Poorly nourished cow ...	8.60	3.55	0.80	3.95	
Well-nourished cow. ...	11.94	3 75	3.40	4.54	
Poorly nourished cow ...	11.70	2.41	2 98	6.07	0.24
Well-nourished cow..	14.21	2.65	4.46	6.71	0.39

* Monvoisin, Le Lait.

The results of an experiment on the effect on milk composition of changing rations are given in the following table.

EFFECT OF CARBONACEOUS NUTRIENTS ON THE COMPOSITION OF MILK

	Fat		Albuminoids		Lactose	
	Cow I	Cow II	Cow I	Cow II	Cow I	Cow II
Hay alone.........	3.29	2 72	2 08	2 35	3.98	3.97
Hay and starch....	3.29	2 31	2.19	2.78	4 16	4.14
Hay and fat.......	3.29	2.78	2.29	2.77	3.75	3.67
Hay and sugar.....	3.45	2.17	2 45	3.04	3.40	4.04

In this experiment the fat content was least affected; and all the variations may be considered normal, rather than due to the different feeds.

It is a well-known fact that cows give more milk when they are fed on green feeds. At the same time, many people believe that the milk becomes poorer. It is true that summer milk is usually poorer than winter milk, but it is a mistake to attribute this mainly to the great quantity of grass eaten in summer. The influence of grass feeding is indirect: by increasing the flow of milk it does slightly lower the fat content. The season of the year has more to do with the difference between summer and winter milk than has the succulent feed, as will be shown later.

INFLUENCE OF GREEN GRASS ON THE COMPOSITION OF MILK

(After Orla-Jensen)

	Density	Solids	Ash	Lactose	Fat	Albuminoids
Dry ration......	1 0318	12 56	0 71	5.09	3 60	2.95
	1.0329	12 47	0 71	4.24	3 70	2.98
Green ration....	1.0327	12 66	0.72	5 29	3.50	3 04
	1 0341	14 26	0 73	5 10	4.67	3 89
Dry ration......	1.0346	14 54	0 75	4 95	4 90	4 00
	1.0345	14.57	0 73	4.86	5 00	4 05

The effect of ensilage on the production of milk is much the the same as that of green grass. As it is a succulent feed, it also stimulates the secretion of milk. Mangels are an even better substitute for green grass than ensilage. To test their effect

on the composition of milk, analyses of milk from cows differently fed were made by Brunel and Goussier, with the following results.

INFLUENCE OF SUCCULENT FEEDS ON THE COMPOSITION OF MILK

	Density	Ash	Lactose	Fat	Albuminoids
Grazing	1.0315	0.65	4.80	3.60	3.60
Ensilage and hay	1.0300	0.58	5.00	3.10	3.60
Hay, mangels, oil meal	1.0320	0.70	5.10	3.20	2.90
Grazing, hay, mangels and oil meal.	1.0320	0.60	5.00	3.80	3.40

Malpeaux [18] made analyses of milk from two cows which were fed mangels and pulp.

EFFECT OF MANGELS AND BEET PULP ON COMPOSITION AND PRODUCTION OF MILK

Cow No. 1	Liters of Milk per Day	Total Solids	Fat	Lactose
Mangel-fed	17.6	12.17	3.47	5.07
Pulp-fed	17.8	12.08	3.37	4.83
Cow No. 2				
Mangel-fed	11.3	12.62	3.46	5.40
Pulp-fed	9.8	13.18	3.69	5.03

The two cows gave almost opposite results, showing that there must be many other factors which influence the composition of milk. The assertion that under normal conditions the composition of milk is not altered by feeding seems justified.

Gautrelet tried the effect of milking a cow immediately after she had drunk a pail of water, comparing the composition of this milk with the normal milk of the same cow. He indicates wide differences, which require further data to confirm them.

PATHOLOGIC MILK

When a cow is diseased the composition of her milk is often affected. Pathologic milk, in general, is not wholesome for human consumption. The diseases that have a direct bearing on alteration in the composition of milk are those affecting the

[18] Memoirs de la Société d'alimentation rationelle du bétail, 1909.

udder. Even when its composition is apparently normal, milk produced by a cow suffering from udder trouble is often dangerous for human consumption. Milk from a cow suffering from a contagious disease is, of course, dangerous.

Van der Laan, testing the freezing points of blood and milk from diseased cows, found a close resemblance between the two. A table of his results follows.

COMPARISON OF FREEZING POINTS OF BLOOD AND MILK

(Degrees C.)

Disease	Blood	Milk
Pyelonephritis	−0.546	−0.547
Tuberculosis of stifle ganglion	−0 541	−0.539
Pulmonary tuberculosis	−0.532	−0.532
Coxal fracture	−0 554	−0.559
Severe hemorrhage	−0.532	−0.533

ANALYSES OF PATHOGENIC MILK

(After Bergema)*

Case	Disease	Date	Casein	Albumin	Lactose	Fat	Acidity	Chlorrine
I	Acute enteritis	I†	2 67	1 13	2 74	4.15	0 70	0.21
		II†	2 27	0 92	4 00	4 20	1.30	0.17
		III†	2.03	0 48	4.74	2.80	1.44	0.12
II	Abdominal paralysis	Nov. 5	1.94	0.85	3.66	3.15	......	0.16
		8	1 79	0.69	4.15	3.20	0.94	0.17
		19	2 01	0.74	4.25	3.50	0.90	0.17
		28	1.68	0.84	4 38	4.10	0.92	0.17
III	Bronchitis	Nov. 20	3.18	0.44	4.90	3.05	1.48	0.11
		30	3 47	0 44	5 00	2 95	1.33	0.11
		Dec. 18	2.78	0.80	5.00	3.50	1.30	0.12
IV	Chronic pneumonia	Nov. 21	2 81	0.82	5.35	1.85	1.30	0.13
		24	2.09	1.20	4.53	1.60	1.30	0.11
V	Metritis	Dec. 8	2.02	0.40	5.10	3.0	1.50	0.13
		14	1 86	0 65	5.18	3 1	1.59	0.12

* Thèse de Berne.

† These three samples taken fourteen days apart; the third after convalescence had begun

OTHER ANALYSES OF PATHOGENIC MILK

Disease	Observer	Total Solids	Albuminoids	Fat	Lactose	Ash
Peripneumonia.	Lajoux	9.87	4.30	2.42	2.27	0.88
Milk fever	Lajoux	16.61	13.21	3.36	2.24	0.82
Same, six days later...	Lajoux	12.22	2.74	3.65	5.23	0.60
Normal milk........ ...	Hess, Schaffer* and Bodzynski	12.25	3.50	3.40	4.60	0.75
Non-infectious mastitis. .	do.	7.15	4.04	0.82	0.53	0.79
Streptococcus mastitis. .	do.	10 66	6.00	1.99	1.84	0.83
Parenchymatous mastitis.	do.	9 74	4.21	2.16	1.01	0.97

* Landw Jahrbuch der Schweitz, 1888.

The increase in albuminoids in mastitis milk is wholly in albumin. The casein tends to decrease. The distribution of nitrogen in mastitis milk is shown in the following table.

NITROGEN IN MASTITIS MILK

	Per Cent of Milk	Per Cent of Total N
Total nitrogen .	1 1440	
Casein nitrogen	0.3990	34.87
Albumin nitrogen	0 5835	51.00
Amide nitrogen..........	0.1615	14.13

Both albumin and amide nitrogen are higher than normal. The increase in ash is due to increased chlorides, as is shown in the following table.

PHOSPHORUS PENTOXIDE AND CHLORINE IN MASTITIS MILK

	P_2O_5 in 100 Grams Ash	Cl in 100 Grams Ash
Normal milk..	26.00	14 00
Mastitis, non-infectious...	7.35	35.76
Mastitis, parenchymatous.	19.21	27.79

When cows are suffering from udder tuberculosis the composition of the milk is affected. Some tables are given to illustrate this.

COMPOSITION OF MILK FROM COWS SUFFERING FROM UDDER TUBERCULOSIS

(Storch)

	Solids	Albuminoids	Fat	Lactose	Ash	NaCl
Normal milk.	11.76	3 02	3 15	4.78	0 78	0.17
Cow III:						
Diseased quarter	6 36	5.22	0 12	0 00	1.02	0.74
Healthy quarter	25 70	11.59	11.79	0.40	1.01	0 50
Cow IV:						
Diseased quarter	10 96	3 03	3 88	2 50	0 79	0 33
Healthy quarter	11 17	2 68	3 15	3 48	0 62	0 15
Diseased quarter	11 69	3 42	5 33	1 27	0 85	0 42
Healthy quarter	18.12	2.73	10.80	3.16	0.65	0.19

Several cases are next described, and the analyses of the milk from them given in the table below.

Cow	Description of Case	Date	No. of Analysis
Healthy.			1
No. 1.	Tubercular udder		
	Mixed milk from all quarters, normal appearance.	Feb. 13, '06	2
		Feb. 15, '06	3
	Milk from healthy quarters, normal appearance.	Feb. 26, '06	4
	Milk from affected quarter, slightly clotted	Feb. 26, '06	5
	Milk from affected quarter, yellowish, clotted	Mar. 5, '06	6
	Milk from healthy quarters, normal appearance	Mar. 6, '06	7
	Milk from affected quarter, yellowish, clotted	Mar. 6, '06	8
		Mar. 8, '06	9
		Mar. 10, '06	10
No. 2.	Tubercular, but with no lesions in udder	Jan. 14, '06	11
No. 3.		July 6, '06	12
No. 4.	Tubercular, with lesions in udder, milk from affected quarters, yellowish, clotted	June 1, '07	13
No. 5.		July 15, '07	14
No. 6.		July 17, '08	15
No. 7.	Milk of normal appearance	Nov. 11, '08	16
		Nov. 14, '08	17

ANALYSES OF MILK FROM ABOVE CASES

No.	Acidity	Total N	Fat	Lactose	Total Solids	Ash	NaCl
1.	0.1543	0.587	4 65	4 35	14 230	0.73	0.1400
2.	0.0895	0.703	2.95	2.46	11.690	0.845	0.2425
3.	0 1140	0 671	1.60	3.12	10 820	0.800	0.2263
4.	0 1018	0.505	2.25	3.87	10.860	0.655	0.2158
5.	0 0530	1 104	1.80	0.77	11 155	0.920	0.4710
6.	0.0692	1.044	0 50	0.48	9.785	0.925	0.4811
7.	0 1384	0 605	0 25	3 82	10.150	0.725	0.1752
8.	0.0530	0 993	0 75	0 35	8 895	0 890	0.4720
9.	0 0407	0 935	0 20	0 42	7 990	0.870	0.4541
10.	0.0244	0 881	0 66	0.29	7.780	0 870	0.4309
11.	0 0664	0.867	2 96	2 98	12 605	0.820	0.4130
12.	0 1292	0 421	5 97	4 39	14 750	0 670	0.1050
13.	0 0124	1.080	0 15	0.00	12 930	0 950	0.4810
14.	0 0249	0 897	0.42	0 00	9 760	0 905	0 4850
15.	0 0228	0.824	0 07	0 00	7 340	0 960	0 5310
16.	0.1015	0 538	4 19	3 00	13 915	0 810	0.4590
17.	......	0.593	3.84	0.946	10.975	0.845	0.4590

The milk from the affected quarters loses lactose almost entirely; the fat usually diminishes; the ash and nitrogen in most cases increase. The increase of total ash seems to be chiefly due to increase in sodium chloride. and that in nitrogen to increase in albumin.

DISTRIBUTION OF NITROGEN IN TUBERCULOUS MILK

		Actual Percentage			Percentage of Total N		
	Total N	Casein N	Albumin N	Amide N	Casein N	Albumin N	Amide N
Normal milk from....	0.43	0.37	0.093	0 013	77.0	15 7	2.5
to......	0.58	0.43	.....	0.024	81.0	17.5	4.7
Tubercular milk, cow:							
No. 7, Nov. 11 . .	0.54	0.30	0.192	0.052	54.6	35.6	9.7
No. 7, Nov. 14 . .	0.59	0 32	0.245	0.030	53 7	41.2	5.1

Milk from diseased udders has a similarity to blood serum. This seems to be explained by the inability of the diseased udder to convert the blood into milk, imperfect conversion leaving the milk much like the serum, with the corpuscles, etc., filtered out.

G. Koestler and E. Elser[19] made a study of the effect of foot-and-mouth disease on the composition of the milk of cows. This disease disturbs the secretory functions and checks milk flow. Its effect on the composition of the milk is much the same as that of an advanced stage of lactation, fat and protein increasing and lactose decreasing. In the following table are average results from four cows studied by Koestler and Elser.

EFFECT OF FOOT-AND-MOUTH DISEASE ON COMPOSITION OF MILK

				Nitrogenous Substances			
	Fat	Lactose	Total	Casein	Soluble	Heat-coag.	Ash
Normal average of four cows.. ..	5 17	4.37	3 62	2 83	0.88	0.46	0.73
Average, foot-and-mouth disease, same four cows.	9.46	3.44	4.40	3 23	1.07	0.67	0.87

When the udder is affected by the disease the fat content usually diminishes, and in some cases fat is absent from the milk of the affected quarters. When the disease does not affect the udder the fat often increases in the milk, because less milk is produced. Lactose is the most constant of all milk constituents, but it is much affected by udder disease and also by severe fevers. Albumin and ash are generally increased by diseases. Of the ash constituents, chlorine increases more than any other, and, with increased chlorine, phosphoric acid generally decreases. Calcium increases in many cases, but the reverse is also often observed. It is not safe to lay down positive rules about the effect of disease on milk, as the constituents of milk vary so much under so many circumstances.

MILK FAT

Milk fat is a mixture of triglycerides of several fatty acids. It contains small quantities of cholesterol, lecithin, and coloring matter. Among the fatty acids present in milk fats, two distinct types may be found: the series whose general formulae are

[19] Landw. Jahrbuch der Schweitz, 1922.

$C_nH_{2n+1}COOH$ and $C_nH_{2n-1}COOH$, respectively. The proportions of these two types in the fatty acids of milk fat are not constant; they vary with the feed used, with the season of the year, with the breed of cow, and with various other factors.

Milk fat is, in general, unique, but sometimes body fat transmigrates into milk. This sometimes happens under abnormal feeding, provided the cow carries enough fat stored in her body, and cases of abnormally high fat are often traceable to this cause. The following table shows iodine numbers of body fats, milk fats, and colostrum fats.

IODINE NUMBERS OF BODY, MILK, AND COLOSTRUM FATS

	Body Fat	Milk Fat	Colostrum Fat
Cow	42 0	32 0	46 1–50.5
Goat	44 1	37 0	46.9
Sheep	45 0	39.0	46.8
Human	61 5	43 0	62.0
Dog	72 7	58 3	
Ass	78 2	72 0	

The iodine number of colostrum is much like that of body fat. It is very possible that the body fat transmigrates into the colostrum. While milk fat has a lower iodine number than body fat, there is evidently a relation between them, as the animals that have high iodine numbers for their body fats also have relatively high numbers for their milk fats. It is evident, therefore, that the characteristics of the milk fat are determined by the characteristics of the animal producing it. It is likely that this is true even of different breeds of cattle. The milk fat of the Guernsey breed is quite different in character from that of the Holstein.

The constituents of milk fat are often divided into two groups, the gylcerides of the volatile fatty acids and those of the non-volatile fatty acids. Spallanzani gives the composition of milk fat as follows: butyrin, 5.080 per cent; caproin, 1.02 per cent; caprylin and caprin, 0.307 per cent; and glycerides of non-volatile fatty acids, 93.593 per cent.

C. A. Brown, Jr.,[20] while he was in Pennsylvania State Col-

[20] Annual Rep. Pa. State Coll., 1899–1900.

lege, studied the composition of milk fat. His results are given in the table that follows.

With Brown's results are assembled those of several other investigators. Some workers use one method and some another, so that there is no very good agreement on the composition of milk fat.

COMPOSITION OF MILK FAT, AFTER SEVERAL INVESTIGATORS

(Fatty Acids Only)

Fatty Acid		C. A. Brown	Richmond*	Kocford†	Bell†	Blyth
Dioxystearic,	$C_{18}H_{34}O$	1.00				
Oleic,	$C_{18}H_{34}O_2$	32 50	33 60	31 11	36.10	40.40
Stearic,	$C_{18}H_{36}O_2$	1 83	1 72	1 83		
Palmitic,	$C_{16}H_{32}O_2$	38 61	24 48	25 62	49.46	47.50
Myristic,	$C_{14}H_{28}O_2$	9 89	19 14	20 13		
Lauric,	$C_{12}H_{24}O_2$	2 57	6 94	7 32		
Capric,	$C_{10}H_{20}O_2$	0 32	1 77	1 83		
Caprylic,	$C_8H_{16}O_2$	0 49	0 51	0 46	2.09	0.80
Caproic,	$C_6H_{12}O_2$	2 09	3 25	1 83		
Butyric,	$C_4H_8O_2$	5 45	3 43	1 37	6.13	3.49

* Richmond, Dairy Chemistry

† Lewkowitsch, Oils, Fats and Waxes

Oleic and dioxystearic are the only two unsaturated fatty acids found. Various authorities deny the possibility of dioxystearic acids being formed in the body, and refer the amount found by Brown to oxidation of oleic acid.

The quantitative determination of the different constituents of milk fat still gives uncertain results. Fractional distillation and fractional crystallization are the two methods generally used, and they are likely to give different results with the same sample. Oleic acid is easier to separate because it belongs to the unsaturated group, and there is fair agreement on this constituent. Palmitic and myristic acids are difficult to separate, and two of the investigators above quoted have not separated them.

All analysts agree that palmitin and olein are the two most abundant fats present in milk. The firmness of butter in warm temperatures depends on the palmitin, olein being much softer. The properties of the fatty acids of milk fat are shown in the table on the next page.

PROPERTIES OF THE FATTY ACIDS OF MILK FAT

	Melting Point, °C.	Boiling Point, °C.	Specific Gravity
Butyric	−7.0°	162°	0.9746 at 0°
Caproic	−1.5°	205°	0.9446 at 0°
Caprylic	16.5°	237°	0.9270 at 0°
Capric	31.4°	269°	0.893 at 30°
Lauric	43.6°	225° at 100 mm.	0.875 at 43.6°
Myristic	53.8°	250° at 100 mm.	0.8622 at 53.8°
Palmitic	62.6°	272° at 100 mm.	0.8527 at 62°
Stearic	69.3°	291° at 100 mm.	0.8454 at 71°
Oleic	14.0°	286°	0.898 at 14°

A homogeneous mixture of these various fats is milk fat. It exists in milk in a state of fine subdivision, in the form of microscopic globules. It was formerly supposed that these were surrounded by a gelatinous membrane which separated them from one another. Most authorities have now abandoned the membrane theory and consider the existence of the globules to be accounted for by surface-tension phenomena. Palmer says that the structure of milk shows a microscopic dispersion of fat, stabilized by a colloidal dispersion of proteins and of dicalcium phosphate. It was formerly thought that the churning process served to break the membrane of the fat globule so as to bring the small globules together into butter grains. Palmer considers that butter is produced from cream by the inversion of an oil-in-water emulsion into a water-in-oil emulsion.

In general, the size of the globules varies from 1 to 30 microns in diameter. The smallest measured by the author was about 0.52 micron, and the largest 30.6 microns. The sizes vary with breeds of cattle and with the different stages of lactation. Individuality also plays an important part in determining the size of the fat globules in milk. The author has found Guernsey fat globules the largest, Jersey next, Ayrshire next, and Holstein the smallest, in comparing these four breeds. Rich milk usually has larger and fewer globules than thin milk. The globules of colostrum are very large. As lactation advances, the size diminishes, and at the end of the period they are very small. The table on page 62 gives numbers and sizes of globules for average milk of the four breeds above mentioned, based on the author's experiments.

Number and Size of Fat Globules in Milk

Breed	Number per Cc.	Average Size
Guernsey	1,439,000,000	5.50μ
Jersey	1,954,000,000	4.05μ
Ayrshire	2,047,000,000	3.97μ
Holstein	2,552,000,000	3.76μ

Generally speaking, milk fat is insoluble in water; Richmond states that it will absorb about 0.2 per cent of water. It is soluble in all the ordinary hydrocarbon solvents, in their halogen derivatives, in sulphuric ether, in carbon disulphide, in nitrobenzene, and in acetone. Alcohol dissolves but little. An appreciable portion of milk fat dissolves in hot amyl alcohol, also in hot glycerol. With esters, milk fat mixes in all proportions.

As stated before, milk fat is a homogeneous mixture of several fats, which are various triglycerides of fatty acids. As the proportions of the different acids vary, the properties of milk fat are not always the same. The hard fats are dissolved in liquid fats, making a homogeneous solid solution at ordinary temperatures. If milk fat is melted and then cooled rapidly, it solidifies; but if the cooling is slow, some of the harder fats solidify and the liquid ones separate. If melting and slow cooling are repeated several times, a saturated solution of solid fats in liquid fats may be obtained. It is said that in such a case about half of the solid fats will be in solution. If the material be filtered, the crystals of solid fat will have a lighter yellow color than the liquid that is filtered through. If the liquid be allowed to stand for some time, more solid fat crystallizes out. The difference of color between the liquid and solid portions is not altogether due to a difference of solubility of the coloring matter, but partly at least to the difference in reflecting power of the liquid and the solid.

König gives the specific gravity of milk fat at 100° C. as 0.867. Stohmann's value at room temperature is 0.9307. C. A. Brown found a range of 0.868 to 0.905 at 40° C., referred to water at 15.5° C. It may be safe to consider the specific gravity of milk fat to be about 0.9 at 60° C., the temperature at which the volumetric testing of milk fat is done under ordinary conditions, in Babcock's and Gerber's methods.

Stohmann gives the viscosity of milk fat at 40° C. as 267.4.

The refractive index of milk fat averages 1.4566 at 35° C., according to Richmond, varying between 1.4550 and 1.4659. Stohmann gives a range of 1.4633 to 1.4659; Skalweit, 1.459 to 1.462.

The calorific value of milk fat is given by Stohmann as 9.231 calories per gram; by Atwater, as 9.32 to 9.362; by Chittenden, as 9.418; by Stohmann and Langbein, with Barthelot's method, as 9.216, and with the Thompson-Stohmann method, as 9.192; and by Gibson, as 9.185.

Various writers have given figures for the mean molecular weight of milk fat, ranging from 696 to 740.

Brown gives 232.7 as the saponification value, or Koettstorfer number, of milk fat. Farnsteiner finds 218.6 for one herd and 219.7 for another. Samuelson gives 216, and Fischer, 245. The general range is between 220 and 236 mg. of KOH required to saponify 1 gram of fat.

Milk fat, as well as other fats, may be hydrolyzed not only by alkalies but also by acids. Strong sulphuric acid breaks it up into fatty acids and glycerol sulphate. The saturated fatty acids are not changed further, but the unsaturated are sulphonated, with the evolution of heat.

The Reichert-Meissl number, or volatile fatty acid number, is given by Meissl as from 26.6 to 31.8; by Sendtner, from 24 to 32.8; by Hager, from 26 to 31.

The Reichert-Wollny number, as determined by various observers, is given in the following table.

REICHERT-WOLLNY NUMBER OF MILK FAT

	Number of Samples	Limits
Allen	2	22.5 -24.5
Stein	7	25.08-31.95
Mansfeld	88	24.42-33.15
Besana	114	21.8 -30 19
Sartori	52	23.59-30.97
Vigna	23	20.68-31.79
Spallanzani	70	20.63-30.6
Longi	26	22 55-28.4
Maissen and Rossi	20	21.56-26.40
Mayer	20	20.3 -33.5
Vieth	236	20.0 -32.5
F. Jean	1	20.75

Oleomargarine has a low Reichert–Wollny number and is distinguished from butter by this test.

The critical temperature of an alcohol solution of milk fat depends upon the composition of the fat. The following table shows the result of the investigations of Crismer.

CRITICAL TEMPERATURE AND INSOLUBLE FATTY ACIDS

Critical Temperature, Alcohol, Sp. Gr., 0.8195	Critical Temperature, Absolute Alcohol	Insoluble Fatty Acids
Below 100° C.	Below 54° C.	86–88
100°–108°	54°–62°	88–90 5
108°–118°	62°–72°	90–93 3
118°–124°	72°–78°	93–95 5

There is also a relation between the Reichert–Wollny number and the critical temperature, shown by the formulae:

R. W. = 129° − critical temperature (alcohol of 0.8195 sp. gr.)

R. W. = 83.5 − critical temperature (absolute alcohol)

The solubility of milk fat in acetic acid was first studied by Valenta. Afterward, Allen and Hurst modified the method. Still later, Chattaway, Pearmain, and Moor improved it. It is now used for the detection of oleomargarine in butter. Critical temperatures with this test follow.

CRITICAL TEMPERATURE IN ACETIC ACID SOLUTION

	Maximum	Minimum	Average
Milk fat	39 0° C.	29 0° C.	36.0° C.
Oleomargarine	97 0°	94 0°	95 0°

Experimenting with the Valenta test, J. H. Johnston found that it is better to use absolute alcohol instead of a mixture of ethyl and amyl alcohols. He states that the Crismer number thus obtained lies between 51° and 56° for milk fat. In most cases

it lies between 53° and 54°. Margarine made from tallow shows a Crismer number higher than 65° and that from vegetable fats is lower than 45°. It is also said that, in the case of old butter, 1.5 times the rancidity, measured with N/10 alkali, should be added to the critical temperature.

As milk fat contains unsaturated fatty acids, it combines with halogens. Brown gives limits of 29.36 to 37.30 for the iodine number of milk fat, with an average of 33.33.

Variation in Fat Content of Milk

Fat is the most important constituent of milk from the financial standpoint, and in creameries milk and cream are paid for on the basis of fat content. In cheese factories also, much consideration is given to the fat content of milk, and it is paid for accordingly. In making condensed milk, all the constituents are conserved, and they all have equal importance in the economical production and nutritive value of condensed milk. Here also, however, the fat content has great importance in determining the quality of the finished product. As has been seen in the table of composition of milk of different breeds, the fat is almost proportional to the total solids, and so is really an index of value for the whole milk. Most progressive condenseries recognize this and pay for milk according to fat content.

Variation According to Breeds of Cattle.—Fat content is a breed characteristic. All constituents vary more or less, but fat most. In the table already given, the order of the pure breeds in fat content is as follows: Jersey, Guernsey, Devon, Ayrshire, Shorthorn, Dutch Belted, Holstein. For total solids, the order is the same; but for solids-not-fat, it is somewhat different. Here the order is as follows: Devon, Guernsey, Jersey, Shorthorn, Ayrshire, Dutch Belted, Holstein.

Within each breed there is considerable variation. Average fat tests given by different authors vary considerably, as shown in the table on the next page.

Average Fat Tests of Dairy Breeds

	Holstein	Guernsey	Jersey	Ayrshire
New York State Experiment Station	3 30	5.30	5.60	3.60
Maine Experiment Station	3.47	....	5.50	3.67
New Jersey Experiment Station (Woll)	3.55	5.09	4.89	3.69
World's Columbian Exposition	...	4.51	4.78	
Louisiana Purchase Exposition	3 43	....	4.70	
British Dairy Farmers' Association	3 41	4 61	4 98	4.19
Wisconsin Experiment Station	3 28	4 77	4.98	4.19
König	3 25	5.11	4 32	3 58
Van Slyke and Publow	3 26	5.38	5 78	3.76
Wing	3.42	5.16	5.35	3.66
Vieth	....	....	5.66	
Bell	...	5 16	5.43	4.24
Goodrich	3.25	4.60	4 58	3.60
New Jersey Experiment Station (Richmond)	3 51	5 02	4 78	3.68
Woll	....	....	5 40	3.60
Race	3 41	5 23	3.60	4 01
Average	3 38	5 00	5.15	3.81

The entire averages for the breeds are somewhat lower than those given for the same breeds in the table of general composition. The order, however, is not changed.

For other breeds, Vieth gives the following figures.

Fat Content of Milk for Minor Dairy Breeds

	Maximum	Minimum	Average
Dairy Shorthorn	10 2	1.3	4.03
Pedigree Shorthorn	7 5	1.9	4 03
Kerry	10 5	1.8	4.72
Red Polled	6.6	2.5	4.34
Sussex	7.6	2.9	4.87
Montgomery	6.5	1.4	3.59
Welsh	8.3	3.0	4.91

Fleischmann gives as an average, for Dutch cows, 11.91 per cent total solids and 3.23 per cent fat; and for German cows 12.25 total solids and 3.40 fat.

Stohmann gives the following for European breeds, omitting those discussed.

	Total Solids	Fat
Tondem, Angler	11.94	3.13
Breitenburger	11.89	3.14
Hollander and Oldenburger	11.96	3.25
Flamlander	11.54	3.31
Ostfriesian	12.05	3.38
Freiburger, Spotted Cattle	12.22	3.69
Simmenthaler, Spotted Cattle	12.74	3.79
Miesbacker	13.21	4.16
Brown Swiss	11 80	3.01
Allgauer	12.12	3.20
Wurtzthaler	13.00	4.21
Zillerthaler, Pinzgauer, Duxenthaler	12 57	3.70

Variation According to Stage of Lactation.—As a rule, in the first stage of lactation, the fat test is low, increasing as the period advances. According to Hill, there are wide variations in the first few weeks after calving, with the first two weeks slightly above the third. Cows coming fresh in the spring show a rapid increase after five months. With those calving in summer, the increase begins earlier, at about three months. Cows coming fresh in the fall give milk of about the same fat content throughout the year, a difference of 0.5 per cent being rare. The greatest difference in fat test during the lactation period found in the case of a herd of 115 cows was 3.06 per cent; the lowest, 0.33; and the average, 1.26 per cent. The average difference for cows fresh in spring was 1.62 per cent; summer, 1.25; and fall, 1.08. The lowest fat test usually comes between the second and fourth months; the highest, after the seventh.

Variation According to Age of Cow.—Many dairymen believe that a cow gives richer milk later in life. This is not true. If a cow is kept in normal health, the fat content of her milk will be the same in each succeeding lactation. The results of investigations by Seuffert are given in the table on the next page.

INFLUENCE OF AGE OF COW ON FAT CONTENT

Age, Years	Number of Cows	Fat Content over or under Breed Average
2	84	+0.1
3	76	+0.1
4	57	+0.1
5	46	0.0
6	41	−0.0
7	23	−0.1
8	20	−0.1
9	14	−0.1
10	23	−0.2
11	13	−0.1
12	10	−0.3
13	8	−0.6
14	6	−0.6

The indications of Seuffert's figures are exactly opposed to the idea that older cows give richer milk.

Influence of Feeds on Fat Content of Milk.—This matter has already been mentioned under the general analysis of milk, in connection with the supposed dependence of constituents on feed. The statement there made that the analysis of milk does not in general depend on feed applies equally to fat content. Many early investigators studied this problem, and very conflicting results were reported. With improvement in experimental methods and increased knowledge of the principles of animal nutrition, the matter has gradually been cleared up, and now authorities generally are agreed that fat content cannot be permanently changed by a change of feed. As already explained, a change of feed, by improving the general vigor of a cow, may for a time increase the fat content of her milk, but when she becomes used to the new feed the milk analysis returns to normal.

Hill, of the Vermont Experiment Station, made careful experiments and came to a negative conclusion. Jordan and Haecker support his view. The New Jersey Experiment Station, as a result of changing feeds, report a change of 0.2 per cent in fat

content; but they conclude that this change was not due to the changed feed. Babcock and his co-workers of the Wisconsin Experiment Station have investigated the problem and give a negative decision. At the International Dairy Federation, held in 1911 at Stockholm, Sweden, many dairy investigators from all over the world discussed the same subject, and almost all agreed that feeds have no direct relation to changes in the fat content of milk. This must not be held to mean that temporary change is not possible. Ingenious dairymen sometimes resort to a change of feed to produce a temporary rise in the fat content of the milk of a particular cow, but the increased fat test does not continue beyond a very few days.

Influence of Flow on Fat Content.—This matter also has been referred to in an earlier section. The general fact seems to be that, both in breeds and in individuals, a more voluminous flow is accompanied by low fat test. This is not true in all cases, but is a general principle. A case in point is the fact that as the milk flow diminishes with advancing period of lactation, the fat content rises.

Relation of Time of Milking to Fat Content.—This subject has already been discussed. The larger fat content of morning or evening milk, as shown by Fleischmann and others, is probably due to the fact that there is a longer time between milkings in one case than in the other, the longer period producing more milk of a slightly lower fat content. In winter, evening milk is richer, and in summer the reverse is in general true. When, however, there are three milkings, the noon one is in general higher, but this is again probably due to the slightly shorter period before the noon milking. The slenderness of the basis for any claim to difference due to time of day is shown in the table on the following page, taken from experiments by the author.

Comparison of Morning and Evening Milkings, Fat Percentage

Month	Total Number of Tests	Number Higher in A.M.	Number Higher in P.M.	Number Equal A.M. and P.M.	Percentage Distribution		
					Higher A.M.	Higher P.M.	Equal
August....	191	56	110	25	29 3	57.6	13.1
September.	380	79	285	16	20.8	75.0	4.2
October ..	377	82	263	32	21 7	69.8	8.5
November	320	100	193	27	31 3	60.3	8.4
December..	800	369	357	74	46 2	44.6	9.2
January ..	695	276	348	71	39 7	50 1	10.2
February..	474	190	230	54	40 1	48.5	11.4
March....	452	206	188	58	45 6	41.6	12.8
April.. ..	36	18	14	4	50.0	50 0	11.1

Daily Variation.—If herd milk be tested from day to day there will be little difference from one day to the next; but tests of the milk of one cow often show considerable variations.

According to the report of the Delaware Experiment Station, the least daily mean fluctuation is 0.03 per cent; the greatest, 1.1 per cent; and the average, 0.62 per cent.

The author made a study of the daily variation of fat tests and found that the degree of fluctuation depends upon the length of the period for which daily tests are made. When the period is long, the degree of fluctuation becomes greater as shown in the table.

Variation of Daily Fat Test

Period	Percentage of Fat			Range of Variation	Variation per 1 Per Cent of Average Tests
	Highest	Lowest	Average		
30 days.........	4 10	3 36	3 93	0 74	0.188
120 days.........	6 01	3.68	4.66	2 38	0.511
150 days.........	7 12	3 86	5 16	3 26	0.632

Standard Deviation of Daily Fat Test

Testing Period	Standard Deviation
150 days, 5 months	0 548
120 days, 4 months	0 450
30 days, 1 month	0.283

The standard deviation varies not only with the length of the period of testing, but also with the percentages of tests. With a high-testing milk, the standard deviation is higher than with lower-testing milk.

Standard Deviation of Daily Fat Test with Reference to the Percentage of Test

30-Day Period		120-Day Period	
Average Test	Standard Deviation	Average Test	Standard Deviation
3 33	0.224	4.08	0.338
3 60	0.299	4.52	0.434
3.87	0.275	4.80	0.469
4.70	0.311	4.84	0.452
		5.05	0.489

It may therefore be considered a natural variation when fat tests vary ±0.283 per cent from the average for a thirty-day period, ±0.450 per cent for a 120-day period, and ±0.548 per cent for a 150-day period. When, however, the average test is low, the probable variation is smaller than when it is high. For the thirty-day period only ±0.224 per cent variation is found for samples whose fat test averages 3.33 per cent, while for cows testing an average of 4.7 per cent, ±0.311 is allowable. In the 120-day test the influence of higher fat content in enlarging the standard deviation is also shown. These figures must not be considered as definitive; they are simply the results which the author has calculated from several hundred daily fat tests of individual cows in connection with feeding experiments.

Seasonal Variation.—There has been much discussion of seasonal variation in the fat content of milk, and contradictory results have been published. Unless the number of cows included in the tabulation is very large and the other modifying circumstances, such as season of calving, are eliminated by uniform distribution throughout the year, tables of seasonal variation are likely to be deceptive. Richmond states (1) that milk is rich in November, December, and January, both in fat and in solids-not-fat; (2) that in February, March, and April the fat falls off but the solids-not-fat do not show appreciable diminution; (3) that in May, June, July, and August the fat is low; and

(4) that in September and October an improvement both in fat and in solids-not-fat is noticed.

Tests from all the cows in the herd of the Kansas State Agricultural College, from 1898 to 1911, showed the lowest monthly average for August and the highest for January. A set of 164 cows that have complete yearly records show the highest monthly average in December and the lowest in July. Another set of 186, having complete yearly records, show a similar variation but with the lowest in August instead of July. Ninety-six cows whose calving times are equally distributed throughout the year show the highest monthly test in December and the lowest in August. The data thus far given relate to European and American conditions. The following table gives results obtained in connection with the manufacture of condensed milk at Sapporo, Hokkaido, Japan, the milk gathered for this condensery including about half of the production of the neighborhood. These figures were obtained under the author's supervision.

MONTHLY MILK-FAT TESTS IN THE VICINITY OF SAPPORO, JAPAN

Month	1915	1916	1917	1918	1919	1920	1921	1922	Average
January	......	3.93	3 90	3 85	3.82	3 90	3.70	3 50	3 80
February	...	3 66	3 83	3 78	3.71	3 80	3.50	3 40	3 67
March	3 29	3 64	3 60	3 55	3 59	3 70	3 30	....	3 52
April	3.24	3 58	3.49	3 41	3 40	3 50	3 20	...	3 40
May	3 31	3 43	3.40	3 38	3 43	3 30	3 20	..	3 35
June	3 28	.3 36	3.40	3 37	3.51	3 30	3.20	....	3 35
July	3.45	3 39	3 40	3 36	3 44	3 20	3 20	..	3 35
August	3.43	3.42	3 36	3 42	3 38	3 10	3 10	...	3 31
September	3.56	3 54	3.56	3 46	3.25	3 30	3 30	......	3 42
October	3 87	3.74	3 67	3 54	3.63	3 50	3 40	......	3 62
November	4.00	3.80	3 78	3 69	3 99	3 70	3 30	.....	3 75
December	4.05	4.02	3.91	3 82	4 00	3 80	3.50	.....	3.87
Average	3.55	3 63	3 61	3 55	3 60	3 50	3.33	...	3.535

These results accord with corresponding figures for Europe and America, indicating a persistent tendency for the fat test to be higher in the colder part of the year. Ragsdale and

Turner's tabulation of results from 3763 Guernsey cows confirms the other data referred to, the highest test being in December and the lowest in August.

Influence of Calving Time on Fat Content of Milk.—Fall-calving cows give milk whose fat content is rather constant throughout the year. This is due to seasonal and lactation influences. It has been suggested that, in order to get higher fat figures for advanced registry tests, it may be advantageous to have cows come fresh in the fall. The data given by Ragsdale and Turner do not bear out the supposed higher fat content throughout the year of fall-calving cows. The table that follows shows their results.

AVERAGE YEARLY FAT TESTS OF MILK ARRANGED ACCORDING TO MONTHS OF CALVING

Month of Calving	Holstein, 95	Jersey, 299	Guernsey, 3763	Average 4157
January	3 00	5.29	5.04	4.44
February	3 21	5.47	5 09	4 59
March	3 19	5 24	5.07	4.50
April	3 25	5 50	5 09	4 61
May	3 11	5 46	5 12	4.56
June	3 08	5 40	5 06	4.51
July	3 46	5 02	5 15	4.54
August	3 05	5 49	5.12	4.55
September	3 18	5 50	5 09	4.59
October	3 03	5 25	5.01	4.43
November	3.16	5 35	5.03	4.51
December	3 07	5 51	5 09	4.56
Average	3.15	5.37	5 08	4.53

Variation of Fat Percentage in Different Portions of Milking.—There is wide variation in fat content between different portions of the milk drawn at one milking. The very first portion is almost like skimmed milk, and the last part is very much richer. J. B. Boussingault divided one milking into six parts and tested them for butter fat. His results were as follows: (1), 1.70; (2), 1.76; (3), 2.10; (4), 2.54; (5), 3.14; (6), 4.08; whole, 2.55 per cent. The cow chosen was a very low-test one.

F. E. Emery tested the first and last portions of a milking with the following results: Morning milking: first part, 1.20;

last part, 8.40; entire milk, 4.40. Evening milking: first ten streams from each teat, 1.00; second part of milking, 5.80; strippings, 9.00; entire milk, 5.00 per cent.

Variation in fat content of farmers' milk is often due to imperfect milking. F. W. Woll found that the strippings obtained by the Hegelund method of manipulation tested, on an average, 10.32 per cent. In one case, as high a test as 23 per cent was obtained for strippings. The highest test of strippings obtained by the method for a herd was 14.41 per cent. These instances show the importance of drawing the last milk from the udder, not only for improving the average quality of the milk, but also because the milk flow is stimulated by thorough milking.

Variation of Fat Content of Milk with the Environment of the Cows.—W. D. Hoard once said that to stick a pin in a cow not only decreased the flow of milk but diminished the fat percentage. These words are, of course, an exaggeration, but they point truly to the importance of the environment of the cow as affecting not only the yield of milk but also its quality. Farrington and Woll state that the percentage of fat in milk is affected by change of milkers, by rapidity of milking, by rough treatment, by exposure to rain and bad weather, and by unusual excitement or sickness. These things affect the fat content, either directly or indirectly. Change of milkers usually lowers the percentage, because the cow "holds up" her milk if milked by a stranger, and the last portion is not drawn. This is especially true if a poor milker takes the place of a good one.

It is the author's experience that older cows do not do as well with machine milking as younger ones, and this is confirmed by others who have made observations on the effect of milking machines on yield of milk. The older cows have been used to hand milking for so long that the new method disturbs them. The young cows, starting with machine milking, are almost indifferent as to whether they are milked by hand or by machine.

When the milk is drawn from the udder rapidly the fat percentage is higher than when the cow is milked slowly. This has no reference to the rapid motion of the hands, but simply to the rate of flow of milk into the pail.

As already stated, the fat percentage is unfavorably affected by rough treatment, exposure, excitement, and sickness. In

general, anything that causes diminished milk yield also diminishes the fat percentage. The effect of various diseases on the constituents of milk has been discussed.

The influence of work on the composition of the milk has also been discussed in the section dealing with normal milk. Morgen and Stillich find slightly increased fat content in the case of cows doing light work, with diminished total milk yield. It may be true that cows are the better for light work if the

Fig. 18.—A University Herd in Japan.
The Hokkaido Imperial University, Sapporo. Holsteins and Guernseys.

alternative is standing in the stable all the time; but if they have proper exercise every day, work is not advisable.

LACTOSE

There is said to be a trace of monosaccharid in milk, but the important carbohydrate is lactose, commonly called milk sugar. It is a disaccharid and has the empirical formula $C_{12}H_{22}O_{11}$. It is found in the milk of almost all mammals.

Although lactose is one of the products secreted by the mammary glands, and is normally found only in milk, it appears in the urine when milk is retained in the udder, being excreted

by the kidneys under such conditions. If the milk glands are taken off before calving, lactose will never be formed. The fact that the dextrose content of blood from the mammary vein is less after calving than that of the blood from the jugular vein is an evidence that the dextrose of the blood is the supply for the production of lactose in the milk glands.

Lactose occurs in two forms, known as the alpha and beta modifications. When lactose is allowed to crystallize from its water solution, the alpha modification is obtained, in the form of rhombic prisms. This form exhibits multirotation. The specific rotation gradually decreases on standing. For a short time after the solution is made, the length of time depending on the temperature, the specific rotation is $[\alpha]_D = +84.0$. A

PHENYLLACTOSAZONE. PHENYLGLUCOSAZONE.

FIG. 19.

Osazone crystals are found in abundance in sweetened condensed milk. Under the action of phenylhydrazine hydrochlorate and sodium acetate, lactose forms phenyllactosazone.—After Monvoisin.

gradual decrease goes on until the specific rotation reaches + 52.5, the value for the stable variety of lactose, which has one molecule of water of crystallization. The corresponding figure for anhydrous lactose is + 55.3. Anhydrous lactose that is obtained by heating the alpha modification to 130° C., does not exhibit multirotation. Anhydrous lactose that is obtained by evaporating lactose solution very rapidly and letting it crystallize instantaneously, shows a specific rotation of $[\alpha]_D = 32.7$. Its birotation ratio, that is, $\frac{\text{initial rotation}}{\text{final rotation}}$, is the same as that of the alpha modification, 1.6. The specific gravity of the alpha modification is 1.545 at 15.5° C., referred to water at 15.5° C. Ten

grams dissolved in 100 cc. of water give a solution whose specific gravity is 1.0391; $\frac{15.5°}{15.5°}$. Its specific rotation is $[\alpha]_D = +52.5$ at 20° C., decreasing by 0.075 for each degree rise of temperature. The refractive index of a 10 per cent solution at 20° C. is 1.3461, that of a 5 per cent solution being 1.3395.

Lactose is not fermentable by ordinary yeast (*Saccharomyces cerevisiae*), and it is unalterable by ordinary enzymes; but it is hydrolyzed by lactase into dextrose and galactose. It is said that this lactase is the endo-enzyme of *Torula kefir* and *T. tyrcola*. It is present in kefir grains as exo-enzyme. Lactase is also widely distributed in animal systems. It is abundantly present in the stomachs of sucklings and may be found in muscle tissue and in the liver, lungs, and pancreas.

The most important product of the fermentation of lactose is lactic acid, $C_3H_6O_3$, which has four different isomers. Of these, three have the constitutional formula $CH_3 \cdot CH(OH) \cdot COOH$, which is the same as alpha-hydroxy-propionic acid. The fourth has the constitutional formula $CH_2(OH) \cdot CH_2COOH$, which is hydrocrylic acid or beta-hydroxy-propionic acid. When milk is soured naturally, the last form is not produced. What concerns us, therefore, is the alpha-hydroxy-propionic acid type. This has an asymmetric carbon atom:

$$\begin{array}{ccc} & H & \\ & | & \\ CH_3 - & C & - COOH \\ & | & \\ & OH & \end{array}$$

It has, therefore, three possible isomers, exhibiting three different rotations, laevo, dextro, and neutral, classified as laevo, dextro, and racemic or inactive lactic acids. Both dextro and laevo rotatory acids are produced in the natural souring of milk; therefore, the acid produced under ordinary circumstances is largely of the racemic (dextro plus laevo) variety, unless pure cultures are used.

The specific gravity of lactic acid at 15° C., with reference to water at 4°, is 1.2485; and its refractive index at 20° C. is 1.4469. When a water solution of lactic acid is evaporated, 2 molecules of lactic acid lose a molecule of water, and lactic anhydride or

dehydrolactic acid, $C_6H_{10}O_5$, is produced. When evaporation is continued at a high temperature, lactide ($C_6H_8O_4$) is finally produced. The boiling point of lactic acid is 83° C. at a pressure of 1 mm. of mercury, and 119° C. at 12 mm. Lactic acid is insoluble in petroleum ether but soluble in alcohol and ordinary ether.

Lactic acid forms salts with various metals. The calcium salt crystallizes with 5 molecules of water. It is soluble in cold water to the extent of 9.5 per cent. Zinc lactate, $ZnC_6H_{10}O_4 \cdot 3H_2O$, dissolves in cold water only to the extent of 1.8 per cent. It is ten times as soluble in boiling water. It crystallizes in well-defined monoclinic prisms.

As has been stated, the lactose content of milk varies less than any other constituent. It is approximately 5 per cent in cow's milk, being affected little by varying circumstances, except disease or other physiological disturbance. Variations in the lactose content of pathological milks have been discussed. In severe cases of disease of the udder, lactose may almost disappear from the milk.

G. Koestler, of the Swiss Dairy and Bacteriological Experiment Station, found that retention of milk in the udder causes a considerable change in its constituents. The lactose content in one case decreased from the normal 5 per cent to 1.75 per cent.

While lactose is one of the most important nutrients in condensed milk, it sometimes causes trouble by giving a sandy or gritty character to the product, in consequence of crystallizing in rather large crystals. Lactose is less soluble in water than any other disaccharid. Therefore, when milk is condensed it crystallizes out. If the crystals are small enough they are not noticeable. This matter will be discussed at length in the chapter on the technology of condensed-milk manufacture. It was studied by Leighton and Peter of the United States Department of Agriculture, and reported on at the World's Dairy Congress, held in America in 1923. (See Proceedings of the World's Dairy Congress, 1923, p. 477.)

PROTEIDS

The proteids of milk are as follows:

Casein (caseinogen)......	approximately 2 to 3 per cent
Lactalbumin	approximately 0.3 to 0.8 per cent
Lactoglobulin	trace
Mucoid proteids.........	trace

Casein belongs to the acid phosphoproteids which do not contain purine nor pyrimidin. Lactalbumin is, as its name implies, an albumin, soluble in water and coagulated by heat. Globulin is insoluble in water but soluble in a solution of common salt. Richmond states that the casein of milk precipitates by saturation with common salt, magnesium sulphate, or ammonium sulphate. Globulin is soluble in a saturated solution of salt, but separates out with the addition of magnesium sulphate and ammonium sulphate. Lactalbumin is soluble in saturated solutions of both salt and magnesium sulphate, but is precipitated by saturation with ammonium sulphate. It is precipitable by magnesium sulphate in slightly acid solution, but, on neutralizing the liquid, it may be brought back into solution. As these reactions are relative in nature and not specific, it is difficult to apply them for the separation of the proteids of milk, for quantitative analysis; but it is possible, by repeating the precipitation with these salts, to obtain pure protein.

Casein is also separable by rennet enzyme (chymase), and lactalbumin may be separated by applying heat, whereby it is coagulated and precipitated. Both casein and albumin are precipitable by the addition of $CaCl_2$ to milk previously heated to 35° to 40° C. All of these three proteids are soluble in alkalies and insoluble in ether and alcohol. Their compounds with heavy metals, such as copper, mercury, and others, are all insoluble. All the proteids of milk are completely precipitated by tannin and by phosphotungstic acid.

Casein

Casein is the most important milk protein, because of its commercial value and the proportions in which it is present. In normal milk, approximately 80 per cent of the total protein is

casein, and it is the chief nitrogenous nutrient of milk. It is fundamental in cheese making.

Pure casein is a white, amorphous solid, without taste or odor, insoluble in water. Its specific gravity is 1.257. On account of the stability of the additive compounds of calcium caseinate and calcium phosphate, the preparation of pure casein from milk is very difficult. Crude casein is prepared from skimmed milk or buttermilk by natural souring or by treatment with hydrochloric or sulphuric acid. The coagulated casein is washed with water and dried.

Van Slyke [21] has prepared very pure casein in the following manner: Freshly separated skimmed milk (unheated and undiluted) is mixed with acid of normal concentration, preferably hydrochloric or a mixture of hydrochloric and acetic. The acid is added slowly and the milk kept in brisk agitation with a special stirrer. When near the isoelectric point, the mixture is allowed to stand three or more hours, under gentle agitation, to complete the reaction, after which more acid is added until the isoelectric point (pH 4.6 to 4.7) is reached. The casein is separated by centrifuging and washed several times by centrifuging with water. It is then centrifuged with strong alcohol, then with ether, and finally with petroleum ether. The last traces of salts are removed by electrolysis.

The composition of casein is variously given by different authors. Before the new method of preparing pure casein, described above, was devised, it was very difficult to remove the last traces of calcium simply by repeated precipitation and resolution. When a few drops of glacial acetic acid are added to milk previously diluted with water, the casein is quickly precipitated. The precipitate may be redissolved by the addition of a small quantity of caustic alkalies, alkaline earths, or ammonia, the carbonates of these, or their bicarbonates or phosphates.

According to Schryver's investigation, when the casein which is precipitated by acetic acid is left at room temperature with excess of acid (1 in 1000) or heated with water at 37° C., the solubility in lime solution is reduced to one-third that of natural casein. Schryver named this substance "metacaseinogen." Its

[21] Proc. World's Dairy Congress, 1923, p. 1148.

solution in half-saturated lime water is opalescent and not opaque. Metacasein, when dissolved in sodium hydroxide solution and quickly precipitated with acetic acid, returns to the condition of ordinary casein, with which it is identical in composition.

The elementary composition of casein, as reported by various authors, is shown in the following table.

ELEMENTARY COMPOSITION OF CASEIN

	C	H	O	N	S	P
Hammarsten (1883–1885)..	52 96	7.05	22.73	15.65	0.76	0.85
Chittenden and Painter (1887).	53.30	7.07	22.03	15.91	0.82	0.87
Lehmann and Hempel (1894) .	54 00	7.04	....	15 60	0.77	0.85
Ellenberger (1902)	53.07	7.13	21.74	15.64	0.76	0.80
Lacqueur and Suckur (1903)	...	....	.....	15.45	0 76	0.77
Burow (1905)..............	52 82	7.09	22 92	15 64	0 72	0.81
Tangl (1908).	52 69	6 81	23.14	15.65	0.83	0.88
Van Slyke and Bosworth (1913)	53.17	7.09	22 48	15.67	0.77	0.82
Geake (1913)...............	53.20	7.09	22.34	15 63	1.015	0.73

Most of the samples whose analyses are given above were obtained by Hammarsten's method. The repeated precipitation of alkaline casein solution with acid in this method tends to separate more or less sulphur from casein combination, as that part of the casein molecule which contains sulphur is slightly unstable. Lehmann's casein was obtained by filtering through a porous plate, and, therefore, some of the lime salts of milk, which are in additive combination with casein, seem to remain.

Casein is very complex in molecular composition or structure. From the percentage elementary composition, Richmond calculated an empirical formula, $C_{162}H_{258}N_{41}SPO_{52}$. To support this formula, he made the following experiment: He treated N/100 K and Na carbonate solutions with an excess of casein and found that 100 cc. of either solution dissolved 1.83 grams of casein. If calculation is made from the proposed formula, 1.84 grams of casein should be dissolved. Race obtained, as the solubility of casein in N/100 KOH, 1.83 grams per 100 cc. This result was obtained at a room temperature of 67° F. At other

temperatures the solubility varied. Therefore, Race concluded that the solubility of casein in alkali solution gives no evidence in regard to the constitution or weight of the molecule of casein.

The following figures show the percentage elementary composition of the casein of milk from different mammals.

Elementary Composition of Casein

		C	H	S	P	N	O
Tangl	Cow	52.69	6 81	0.832	0.877	15.65	23.141
	Buffalo	52.88	7.81	0.833	0.773	15.78	21.925
	Sheep	52.92	7.05	0.717	0.809	15.71	22.794
	Goat	52.90	6 86	0 700	0.760	15.48	23.300
	Mare	52.36	7.09	0.528	0.877	16.44	22.705
	Ass	52.57	7.01	0.588	1.057	16.28	22.495
Ellenberger	Ass	54 90	7 15	1 100	0.510	15.76	20.58
	Cow	53 07	7 13	0.760	0.800	15.64	22.60
Burow	Cow	52 825	7 095	0 725	0.808	15.64	22.906
	Goat	52.805	7 020	0 718	0.815	15.64	23.002
	Dog	52 865	7.045	0 733	0 810	15.595	22.952

The elementary composition of casein from different mammals is comparatively alike. While there are some differences, they are within the limits of variation for the composition of the casein of cow's milk, as stated in the preceding table by different authors. The percentage elementary composition of casein from human milk is as follows:

Elementary Composition of Casein from Human Milk

	C	H	N	S	P
Wroblewski	52 24	7.32	14 97	1.12	0.68
Bergell and Langstein I	53 01	7 14	15.60	0.71	0.25
II	52.63	6.94	14 34	0.85	0.27

The phosphorus content is decidedly small in the results of Bergell and Langstein's analyses. This may be accounted for by the method of analysis, for the result obtained by Wroblewski is similar to that obtained with other casein, except in sulphur content, which is higher than in any other case. While it is

possible that casein from different mammals may differ in some respects, for the behavior of the casein of cow's milk is much different from that of the casein of human milk, the general composition does not vary materially. The behavior of casein depends upon the salts and other substances present in the milk in solution. Therefore, the composition cannot be judged from the behavior in milk.

Various suggestions have been made in regard to the form in which casein exists in milk. Van Slyke believes that it is in combination with calcium as a salt, calcium caseinate. Söldner reports that there are two cases of casein, combined with calcium, namely, 1.11 per cent and 1.16 per cent calcium combined with casein. Lehmann reports that the casein he obtained by the filtration method contained 1.02 to 1.25 per cent of calcium. Van Slyke and Bosworth obtained four different compounds of casein with calcium, the calcium contents being 0.22, 0.44, 1.07, and 1.78 per cent. They also obtained casein combinations with ammonia, sodium, and potassium; ammonia, 0.2 per cent; sodium, 0.26 per cent; and potassium, 0.44 per cent.

As to the acidity of casein, many investigators agree fairly well in their results.

ACIDITY OF CASEIN

	1 Cc. N/10 NaOH Equals	1 Gram Casein Equals
Lacqueur and Suckur	0 1138 gram casein	8 81 cc. N/10 NaOH
Mathaiopoulos	0 11315	8 84
Long................	0 1124	8 90
Van Slyke and Bosworth	0 1111	9 00

By analyzing the calcium salts of casein, Van Slyke and Bosworth considered the casein as an octobasic acid, and classified the salts as follows:

Grams per 100 Grams Casein Ca	CaO	Name of Compound	Reaction to Litmus	Phenolphthalein	Valencies Satisfied
0.22	0.31	Monocalcium caseinogenate.	....	....	1
0.44	0.62	Dicalcium caseinogenate....	....	....	2
1.07	1.50	Neutral Ca caseinogenate...	neutral	acid	5
1.78	2.50	Basic Ca caseinogenate.....	.	neutral	8

From the dissociation value of casein, Lacqueur and Suckur stated that the casein was either a pentabasic or a hexabasic acid. Later, Robertson studied the physical properties of casein, and stated that it was an octobasic acid. If casein is really an octobasic acid, its molecular weight must be about 8900. Van Slyke and Bosworth stated that the molecular weight of casein was 8888.

The solution of casein in dilute alkali is laevo rotatory. Its specific rotation varies with the concentration and nature of the alkali, being from -94.8 to -111.8 The soluble salts of casein may be divided into two groups. One group consists of the salts with alkaline earths, and the other of the salts with alkalies. According to the investigation of Osborne, the former cannot be filtered through the Martin gelatin filter, and the solution is opalescent; while the latter can go through the gelatin filter, and the solution is translucent. Both kinds of salts, when all the valencies are satisfied, are neutral to phenolphthalein, but a definite change cannot be observed when litmus is used as indicator. The point of neutralization with litmus varies with the concentration. The salts of copper, mercury, and lead precipitate casein in neutral solution, and the salts of mercury precipitate it also in acid solution. Such precipitates do not always have the same composition. They vary under different circumstances. The insolubility of the casein salts of heavy metals is applied in getting protein-free milk serum for polarimetric and refractometric uses.

As shown above, casein has the property of an acid, but in some ways it acts as a base. Casein, when it is combined with an acid, forms a clear solution. According to Long, 1 gram of casein combines with 7 cc. of N/10 sulphuric, hydrochloric, hydrobromic, hydriodic, and acetic acids, and forms soluble salt-like compounds. Some consider that precipitated casein is also an acid-combined compound of casein. But, according to the investigation of L. L. Van Slyke and D. D. Van Slyke, the loss of acid in the precipitation of casein is due to surface absorption and not to combination. The amount of acid so lost depends upon the nature and concentration of the acid, temperature, duration of contact, and degree of agitation.

When formaldehyde acts upon casein the amino group of

casein combines with H·CHO and produces methylene derivatives. Compounds so formed cannot be digested by trypsin; but they can be decomposed by steam, and the formaldehyde may be quantitatively recovered. By the formation of methylene derivatives, the alkalinity of casein exhibited by the amino group disappears. Therefore, the casein salt, which was neutral to phenolphthalein before condensation with formaldehyde, becomes distinctly acid, and can be titrated quantitatively with alkali. This reaction is the basis of the aldehyde value.

Casein is hydrolyzed by the action of pepsin, trypsin, or dilute acids, and produces caseinogen proteoses or caseoses which are soluble in water. These caseoses are classified as proto- and deutero-caseoses according to the degree of solubility in ammonium sulphate solution.

The ultimate products of the hydrolysis of casein are said to be about twenty in number. Of these, the best-known hydroclastic products are as follows:

I. Monoamino Acids

(a) Building Stones of Aliphatic Series

Alanine	$CH_3—CH(NH_2)—COOH$
Serine	$CH_2OH—CH(NH_2)—COOH$
α-Aminovaleric acid	$(CH_3)_2=CH—CH(NH_2)—COOH$
Leucine	$(CH_3)_2=CH—CH_2—CH(NH_2)—COOH$
Aspartic acid	$COOH—CH(NH_2)—CH_2—COOH$
Glutamic acid	$COOH—CH(NH_2)—CH_2—CH_2—COOH$

(b) Building Stones of Aromatic Series

Tyrosine	$\overset{OH}{C_6H_4}—CH_2—CH(NH_2)—COOH$
Phenylalanine	$C_6H_5—CH_2—CH(NH_2)—COOH$

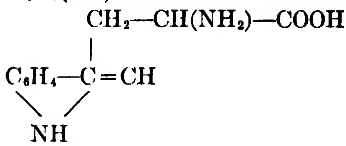
II. Diamino Acids

Diaminotrioxydodecanic Acid	$C_{11}H_{18}(OH)_3(NH_2)_2—COOH$
Lysine	$CH_2(NH_2)—(CH_2)_3—CH(NH_2)—COOH$
Arginine	$NH=\overset{NH_2}{C}—NH—(CH_2)_3—CH(NH_2)—COOH$

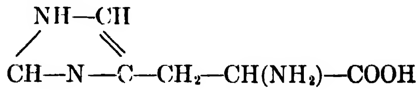
III. Heterocyclic Compounds

α-Pyrrolidincarbonic acid
(proline).................. $C_4H_8N_7$—COOH
Oxy-α-pyrrolidincarbonic acid
(oxyproline).............. $C_4H_7(OH)N_7$—COOH

Tryptophane..................



Histidine......................



IV. Sulphur-containing Amino Acid

Cystine..........COOH—$CH(NH_2)$—CH_2—S—S—CH_2—$CH(NH_2)$—COOH

The amounts of hydrolytic end-products of casein obtained by various investigators are tabulated in the next table. The values for cow's milk are those obtained by Abderhalden, Fischer, Osborne and Greed, Morner, and Hart; those for goat's and human milk are from the work of Abderhalden and Schittenhelm.

Caseinogen Hydrolysis Products

Products of Hydrolysis	Cow's Milk	Goat's Milk	Human Milk
Alanine	0.90	1.50	
Valine	1.00		
Leucine	10.50	7.40	
Phenylalanine	3.20	2.75	
Tyrosine	4.50	4.95	4.71
Serine	0.45		
Cystine	0.06		
Proline	6.70	4.60	
Oxyproline	1.50		
Aspartic acid	1.20	1.20	
Glutamic acid	11.00	12.00	
Tryptophane	1.50		
Arginine	4.84		
Lysine	5.80		
Histidine	2.59		
Diaminotrioxydodecanic acid	0.75		
Aminovaleric acid	7.20		
Ammonia	1.60		

In milk, casein is combined with calcium phosphate and exists in the form of a salt. Many investigators have studied

this substance, but none has come to a definite conclusion. Having analyzed the casein obtained by filtering with a porous cell, Richmond stated that the casein existed in milk in the form of a double salt, calcium sodium caseinogen, with half a molecule of tricalcium phosphate, thus, $C_{162}H_{255}N_{41}SPO_{52} \cdot Ca \cdot Na\frac{1}{2}(Ca_3P_2O_8)$. According to this formula, the amount of acid necessary to displace the Na atom would be 8.3 cc. of normal solution per liter of milk. Richmond demonstrated that when 8.6 cc. of normal hydrochloric or sulphuric acid were added and boiled, the casein was precipitated and the serum showed an acidity equal to that of milk after boiling. L. L. Van Slyke and Bosworth stated that the ordinary method of direct titration for acidity gave erroneous results on account of the presence of calcium salts of phosphoric acid. Cameron and Hurst recognize the following reactions:

$$(1)\quad CaHPO_4 + 2H_2O = Ca(OH)_2 + H_3PO_4;$$

$$(2)\quad 2CaHPO_4 + Ca(OH)_2 = Ca_3P_2O_8 + 2H_2O.$$

In this case there is free phosphoric acid instead of neutral dicalcium phosphate, and it causes higher acidity. The acidity of the serum obtained by filtering milk through a porcelain filter is about half that of the original milk. According to Van Slyke and Bosworth, if, before the acidity of milk is tested, the lime salts are precipitated with neutral potassium oxalate, the acidity of the milk serum is the same as that of the original milk after the precipitation of the lime salts. They say that the caseinogen-calcium phosphate complex is not acid to phenolphthalein, but is neutral.

The action of rennin, a lab ferment, on the casein of milk is very important, not only from a practical but also from a scientific standpoint. Many investigators have made studies on this subject, but its *modus operandi* and the nature of the products are still obscure.

Hammarsten made the most thorough investigation, and his theory was accepted generally until a few years ago. He stated that the casein did not exist in milk as a true solution, but was in a state of colloidal suspension. He demonstrated that, for the coagulation of casein in milk, the presence of a certain amount of calcium phosphate is necessary. By this reaction the casein

is so changed that it can no longer remain in the state of colloidal suspension and finally precipitates as paracasein calcium phosphate in the presence of calcium phosphate. He further stated that the casein was decomposed into two other proteids, paracasein and whey proteid. The calcium salt of the former is insoluble in water, while that of the latter is soluble and the molecular weight is smaller. By analyzing the two products, Koster obtained the following results:

	Paracasein	Whey Proteid
Carbon	52 88	50.33
Hydrogen...........	7 00	7 00
Nitrogen	15 84	13 25
Phosphorus (Richmond). .	0 99	

From the above results Richmond calculated the approximate formulae as follows:

$$\text{Paracasein,}\quad C_{140}H_{222}N_{36}PO_{44};$$
$$\text{Whey proteid,}\ C_{22}H_{37}N_5O_{10}.$$

In conclusion, Hammarsten stated that calcium salt had nothing to do with the splitting of casein into paracasein. This was confirmed by later investigators.

Some chemists (Loevenhart and Briot) believe that the most important part of the rennin reaction is in the modification of mineral constituents; but Harden and Macallum found that if enough rennin be added to casein solution (1 : 1000) calcium salts are not necessary for the coagulation. Schryver states that casein coagulates in the absence of calcium ion. Duclaux was the first to discover that the casein does not undergo hydrolysis by the action of rennin. Van Slyke and Bosworth, Geake, and Harden and Macallum proved this. Loevenhart says that casein and paracasein are chemically identical and that the difference in the behavior of these two substances is due to molecular association or aggregation. According to Van Slyke and Bosworth, one casein molecule is split into two molecules of calcium paracasein by the action of rennin, and the percentage composition of the latter is exactly the same as the original substance.

According to Schryver, Witte's peptone, or glycine, prevents coagulation by rennin; but if calcium chloride is added to calcium caseinogenate solution and warmed, the usual coagulation can

be obtained. The substance so coagulated differs from the ordinary coagulum obtained by rennet. If this coagulum is dissolved in alkali, it can be again precipitated by acid, while the ordinary coagulum obtained by the use of rennin cannot be redispersed. From these facts it may be assumed that the action of rennin brings about a structural change in casein.

Casein is also coagulated by trypsin and other enzymes. There are evidences of proteoclastic cleavage in the coagulation of casein by trypsin. As the results, soluble compounds containing nitrogen and phosphorus are produced.

When milk is heated above 70° C., the rennet action is retarded. This is due to a partial destruction of the enzyme and precipitation of calcium salts. According to Morgenrath, refrigeration prevents the formation of the characteristic curd by rennin, but upon heating the milk to 37° C. this property is regained.

The optimum temperature of rennin is 40° C. As the temperature rises above this point, the rennin action is retarded, until finally the enzyme is entirely destroyed. Until the temperature reaches 40° C., the action of rennin continues to increase.

Other conditions being the same, the time for coagulation by rennin is inversely proportional to the strength of the enzyme. Acids and salts of alkaline earths promote this action; while alkalies, albumoses, and most of neutral salts retard it. When normal horse serum is added to milk, the rennin action is inhibited. The so-called "antirennin" of Morgenrath gives the same result. Morgenrath repeatedly injected rennin into a rabbit and obtained from it the serum which he called antirennin. This inhibitory action of horse serum toward rennin may be prevented by neutralizing with acid (Raudnitz and Jacoby). It may therefore be said that horse serum, or antirennin, inhibits the action of rennin by fixing the calcium ion in the milk.

Lactalbumin

The percentage elementary composition of lactalbumin is given by Sebelien and by Ellenberger as follows:

	C	H	N	S	O
Sebelien	52.19	7.18	15.77	1.73	23.13
Ellenberger	54.47	7.37	15.69	1.32	21.13

The chief difference between casein and lactalbumin is that lactalbumin contains more sulphur and no phosphorus.

Lactalbumin has the same properties as other albumins. It is soluble in a neutral saturated solution of magnesium sulphate, but will be precipitated in the presence of a small amount of acetic acid. If, to the solution of lactalbumin in doubly diluted saturated solution of magnesium sulphate, acetic acid is added, and left until permanent turbidity is formed, lactalbumin crystallizes out.

Lactalbumin is precipitated in milk by saturating with sodium or ammonium sulphate. Tannin and phosphotungstic acid also precipitate lactalbumin. It is insoluble in alcohol. Its water solution is sometimes precipitated with alcohol, and the albumin so precipitated is readily soluble in water.

Pure lactalbumin is a white powder and has no taste or odor. It coagulates at 70° C., but the precipitation is never complete. According to Béchamp, the specific rotatory power is −67.5. Sebelien gives a range of values from −36.4 to −38.0. Lindet states that the specific rotatory power of lactalbumin is −30.0. No two results agree at all well. These conflicting results may be due to impurity of the samples. If a minute amount of casein is contained in the sample as an impurity, the specific rotatory power will be greatly increased.

The hydroclastic products of lactalbumin, as obtained by Abderhalden and Pribram, are as follows:

Alanine	2 5	(2.68)
Valine	0 9	
Leucine	19 4	(20 00)
Proline	4 0	(1 04)
Aspartic acid	1 0	(3 12)
Glutamic acid	10 1	(1 52)
Phenylalanine	2 4	(3 08)
Tyrosine	0.85	(2 1)
Cystine		(2.3)
Serine		(0.6)
Tryptophane		trace

The figures in parentheses are for the albumin crystallized from horse serum.

Lactoglobulin

Some investigations on lactoglobulin have been made. It is precipitated with neutral sulphate salts but is very readily soluble in NaCl solution. In NaCl solution lactoglobulin does not precipitate even upon acidification. It is not coagulated with rennin, but is coagulated by heating to 72° C. or higher. the amount of lactoglobulin present in milk does not exceed 0.1 per cent, but in colostrum a little more may be found. The elementary composition of lactoglobulin may be compared with that of serumglobulin in the following table:

	C	H	N	S	O
Lactoglobulin	49 83	7 77	15.28	1.24	25.88
Ass's milk globulin	53 40	7.31	15.69	0.47	23.03
Serum globulin	52.71	7.01	15.85	1.11	23.32

The first of the above analyses is that of Tiemann; the second, that of Ellenberger; and the third, that of Hammarsten.

Mucoid Proteids

Mucoid proteids are found in the separator slime, and do not have a definite composition. According to Storch, however, they contain 14.76 per cent of nitrogen and 2.2 per cent of sulphur. They occur in the form of a grayish-white powder, and are slightly soluble in dilute KOH and NaOH solutions. They are insoluble in NH_4OH and in acetic and hydrochloric acids. Mucoid proteids exhibit the usual protein reactions. They are positive to Millon's, the biuret, iodine, and xanthoproteic reactions. Upon hydrolysis, they produce a substance which reduces Fehling's copper solution. Some of the end-products of hydrolysis are as follows:

	Per Cent
Tyrosine	2 05
Glutamic acid	8 50
Glycocoll	0 50
Alanine	1 50
Leucine	2.00
Phenylalanine	trace
Aspartic acid	trace

According to Wrobleswki, the elementary composition of mucoid proteids is as follows:

C	H	N	P	S	O
45.01	7.31	15.07	0.80	4.70	27.11

It is said that mucoid proteids are the so-called β-casein of Strewe. Strewe gave the name β-casein to the substance remaining when casein is dissolved with HN_4OH.

Beside the substances which have been discussed above, peptone is said to be present in milk, but its presence is not well established.

ASH

Besides those in combination with casein, there are many salts present in milk serum in solution as well as in suspension. Normal milk contains usually about 0.75 per cent of ash. As with other milk constituents, the ash content is also variable. The ash of milk is composed of various salts which occur in varying proportions. The usual method of determining the ash content of milk is by ignition. By this method some of the organic salts are ignited and lost. Chlorine compounds are likely to be more or less lost by high temperature. Sulphur compounds are subject to modifications. If milk is dried and ignited at a low red heat, however, fairly accurate results are obtainable. According to Richmond, the ash obtained by drying and igniting milk has the following composition:

Composition of Ash of Milk

Lime	20 27
Magnesia	2 80
Potash	28 71
Soda	6 67
Phosphoric acid	29.33
Chlorine	14 00
Carbon dioxide	0.97
Sulphuric acid	trace
Ferric oxide	0.40
	103.15
Less oxygen = Cl	3 15
	100 00

Beside the above, milk ash contains salts of organic acids. Soxhlet and Henkel proved the presence of citric acid in milk.

The composition of milk ash is given differently by different authors. This is due partly, as already pointed out, to the methods of preparing the sample of ash for analysis, but for the most part it is due to differences in composition depending on the individuality of the cow, the stage of lactation, and the health of the cow at the time of milking. The composition of milk ash, according to the findings of different authors, compiled by Monvoisin, is as follows:

COMPOSITION OF ASH BY DIFFERENT AUTHORS

	I	II	III	IV
Sodium chloride	4 74	16 23	4.89	4.43
Potassium chloride	14 18	9 49	29.38	23.86
Potash	23 46	23 77		
Soda	6 96	..	8 57	5.86
Lime	17 34	17 31	25 51	24.25
Magnesia	2 20	1 90	3.87	3.78
Ferric oxide	0 47	0 33		
Phosphoric acid	28 04	29 13	26.32	25 16
Phosphate of iron		. .	1.42	1.26
Sulphuric acid	0 05	1 15		
Carbonic acid	2.50			
Silica	0 06	0 09		

The composition of the ash of milk from different mammals differs, naturally, even more than that of the ash of different samples of cow's milk obtained under various circumstances. The following table gives some analytical results obtained by different authors for various mammals:

COMPOSITION OF MILK ASH FROM DIFFERENT MAMMALS

	K_2O	Na_2O	CaO	MgO	Fe_2O_3	SO_3	P_2O_5	Cl
Human milk:								
Bunge......	32 14	11.75	15.67	2.99	0.27	......	21.42	20.35
Backhaus....	33.74	11.91	17.36	3.17	0.63	5.01	14.79	15.47
Camerer, etc.	32.40	13.10	13.90	1.90	0.07	3.30	11.40	15.47
Cow's milk:								
Schrodt, etc..	25.42	10.94	21 45	2.54	0.11	4.11	24.11	14.60
Fleischmann.	25.71	11.92	24 68	3.12	0.31	......	21.57	16.38
Buffalo's milk:								
Schrodt....	14 16	6.12	33 76	3.24	0.18	2.93	34.04	7.39
Sheep's milk:								
Weiske, etc..	23.80	4.50	27.10	2.08	......	0.80	15.20	6.20
Goat's milk:								
Stohmann.....	....	.....	20 77–30 82	2.75–3.70	......	....	34 12–39.54	
Camel's milk:								
Dragendorff.	19 39	3 42	26 10	4 61	....	3 50	29.21	13.66
Mare's milk:								
Bunge. ..	25.44	3 38	30 09	3 04	0 07	.....	31.06	7.50
Ass's milk:								
Ellenberger..	20 49	8.05	25.85	3.17	0 01	3.41	32 93	7 56
Dog's milk:								
Bunge. .	11.86	5 75	33 74	1 57	0 12	. ....	36.79	13.14
Sow's milk:								
Scheven	6.22	6.73	39.22	1.77	0.87	1 28	37.21	9.32
Rabbit's milk:								
Abderhalden	10.06	7.92	35.68	2.20	0.08	.....	39.86	5.42
Dolphin's milk:								
Abderhalden	9.69	9.00	31 07	3.10	0.17	.....	37.02	12.84

The presence of sulphuric acid in milk is much disputed by authorities. Most of them agree that the amount of sulphuric acid is only a trace, and what appears in the analysis is due to the modification of sulphur contained in the protein of milk. Allemann obtained more SO_3 from ash prepared with Na_2O_2 than from ash prepared by the usual method. This is due to the conversion of SO_2, in which form sulphur is present in the proteins of milk, into SO_3. The results of Allemann's investigation are as follows:

ANALYTICAL RESULTS OF SO_3

	Per Cent SO_3 with Ordinary Method	Per Cent SO_3 by Addition of Na_2O_2	Per Cent SO_3 Calculated from S in Protein	Per Cent SO_3 in Acetic Acid Serum	Difference between Superoxid SO_3 and Protein SO_3
Mixed milk	0.294	0.842	0.560	0.270	0.282
	0.173	1.357	0.521	0.718	0.836
	0.342	0.931	0.500	0.439	0.431
	0.267	0.912	0.578	0.459	0.334
	0.230	1.173	0 511	0 641	0.662
Colostrum.	0.548	4.047	3.501	0.696	0.546
	0.104	4.123	3.625	0.714	0.498
	0.139	3.129			
	0.108	3.146			

Phosphoric acid is present in great quantity in the ash of milk. Its salts form the greater part of the ash, and the phosphorus present in milk in the form of casein has but little relation to the phosphorus content of the ash. The distribution of phosphorus compounds in milk is as follows:

DISTRIBUTION OF PHOSPHORIC ACID IN MILK

	Gram per 100 cc. Milk
P_2O_5 as casein combined with Na and Ca .	0 0605
P_2O_5 as $Ca_3P_2O_8$.	0.0625
P_2O_5 as R_2HPO_4........................	0.0770
P_2O_5 as RH_2PO_4........................	0.0200

By the usual method of ashing, a part of the chlorine is lost. Therefore, it is very difficult to obtain all the chlorine present in milk. To the serum obtained by coagulating milk with acetic acid, potassium nitrate is added and dried. This dried mass is powdered and extracted with water. The extract contains more chlorine. By this method Allemann made the analysis of chlorine in milk. Comparing his results with those obtained by the usual method, he presents the following data:

	1	2	3	4	5	6	7	8
Ordinary method...	0 715	0.824	0.764	0.350	0.777	0.880	0.796	0.726
Improved method..	1.161	0.983	1.045	1.128	1.032	1.100	1.003	1.135

In the preparation of ash by the ordinary method, citric acid is burned off; therefore, it does not appear in the ordinary analysis of milk ash. According to Henkel, normal milk contains from 0.10 to 0.15 per cent of citric acid. Scheibe found citric acid in human as well as in goat's milk. He states that the citric acid content of goat's milk is about the same as that of cow's milk, ranging from 0.10 to 0.15 per cent. Vaudin found from 0.06 to 0.08 per cent in mare's milk. Söldner, on the other hand, found as high as 0.2 per cent. Pappel and Richmond found in buffalo's milk 0.3 per cent of citric acid.

The states of combination in which the various salts are present in milk is rather a matter for speculation. There is at present no satisfactory method of differentiating the various salts as they really exist in milk. Söldner attempted to show probable combinations of acids and bases in milk. His values are given in the following table:

Probable Composition of Various Salts in Milk

	Per Cent of Milk	Per Cent of Ash
Sodium chloride	0 0962	10.62
Potassium chloride	0 0830	9.16
Monopotassium phosphate	0 1156	12.77
Dipotassium phosphate	0 0835	9.22
Potassium citrate	0 0495	5.47
Dimagnesium phosphate	0 0336	3.71
Magnesium citrate	0 0367	4.05
Dicalcium phosphate	0.0671	7.42
Tricalcium phosphate	0 0806	8.90
Calcium citrate	0 2133	23.55
CaO as combined with casein	0.0465	5.13

By analyzing milk and milk serum, Van Slyke and Bosworth showed the distribution of milk constituents in the coagulable and serum parts of milk.

Composition of Milk and Milk Serum

	Original Milk	Milk Serum	Percentage of Milk Constituents in Serum
Sugar	5.75	5.75	100.00
Casein	3.07	.....	nil
Albumin	0.506	0.188	37.10
N in other compounds	0.049	0.049	100.00
Citric acid	0.237	0.237	100.00
Phosphorus (entire)	0.125	0.067	53.60
Phosphorus (organic)	0.087	0.056	64.40
Calcium	0.144	0.048	33.30
Magnesium	0.013	0.007	53.80
Potassium	0.120	0.124	100.00
Sodium	0.055	0.057	100.00
Chlorine	0.076	0.081	100.00
Ash	0.725	0.400	55.20

As to the states of combination of acids and bases in milk, Van Slyke and Bosworth propose the following:

Composition of Salts in Milk

(After Van Slyke and Bosworth)

Protein combined with calcium	3.20
Dicalcium phosphate ($CaHPO_4$)	0.175
Calcium chloride	0.119
Monomagnesium phosphate ($MgH_4P_2O_8$)	0.103
Sodium citrate ($Na_3C_6H_5O_7$)	0.222
Potassium citrate ($K_3C_6H_5O_7$)	0.052
Potassium phosphate (K_2HPO_4)	0.230

It is said that minute traces of fluorine, iodine, silica, acetate, and thiocyanates are sometimes found in milk ash.

There seems to be a certain relation between the ashes of milk and of blood corpuscles. Gorup-Besanez gives the following results of analyses of both ashes.

Analyses of Ashes of Milk and of Blood Corpuscles

	Cow's Milk	Blood Corpuscles
Sodium	6.38	14.26
Potassium	24.71	39.76
Chlorine	14.39	18.10
Phosphates	48.34	56.50

Pathologic milk, in its ash composition, more nearly resembles blood serum than blood corpuscles. Monvoisin gives the following results of analyses.

RELATION OF BLOOD ASH TO ASH OF PATHOLOGIC MILK

	Blood Corpuscles	Normal Milk	Mastitis Milk	Blood Serum
Potash	43	23	7	3
Soda	15	7 to 10	35 to 40	51
Chlorine	30	14	45 to 50	43
Phosphoric acid	14	27	8 to 10	3

In discussing the general composition of pathologic milk, it has already been pointed out that the milk of diseased cows, especially when the udder is attacked, is greatly modified in composition and becomes more like blood serum.

The composition of the ash, as already stated, is variable. As the stage of lactation advances the composition of the ash seems to be modified. Trunz gives the following results of his investigation.

COMPOSITION OF RAW ASH AT DIFFERENT STAGES OF LACTATION

	Cow No 1				Cow No. 2			
	Colostrum	I	II	III	Colostrum	I	II	III
Ash	0.774	0.659	0 663	0.754	0.758	0.709	0.764	0.826
K_2O	22 33	25.51	25.10	19 53	23.12	25.71	24.47	20.31
Na_2O	6.51	5 58	5 32	6 30	6.71	5 88	6.05	10.34
CaO	26 61	25 48	25 53	29 42	23 86	23 38	23.57	22.93
MgO	3 26	2.82	2 77	3 35	3 72	2 77	2 70	2.98
Fe_2O_3	0 43	0.34	0 43	0 37	0 21	0 24	0 23	0.26
Cl	10 63	11 34	10.58	12 87	13 23	13 78	17 05	20.23
P_2O_5	30.34	28.83	30.16	28 71	30 36	28 76	27 26	25.58
SO_3	2.08	2.58	2.47	2.42	1.78	2.46	2.50	1.94

Composition of Pure Ash at Different Stages of Lactation

	Cow No. 1				Cow No. 2			
	Colostrum	I	II	III	Colostrum	I	II	III
Ash	0.705	0 598	0.599	0 675	0.684	0.651	0.701	0.771
K_2O	24 61	28 05	27.57	21.86	25.68	28.51	26.62	22.28
Na_2O	7.14	6 00	6 08	7.05	7.48	6.79	6.63	11.28
CaO	29.27	28 03	28.29	32.83	26.48	24.73	25.74	25.17
MgO	3.58	3.11	3.06	3 75	4.15	3.00	2.92	3.27
Fe_2O_3	0.48	0.40	0.48	0.42	0.23	0.26	0.25	0.28
Cl	11.67	12.60	12 09	14.76	14.70	15.21	18.75	22.19
P_2O_5	25.66	24.50	25.16	22.66	24.60	24.88	23.30	20.54

Schrodt and Hausen studied the variation of the composition of ash at a later stage of lactation. They compared it with the composition of colostrum ash, as follows:

Composition of Ash at First and Later Stages of Lactation

	Later Stage of Lactation	One Day before Calving	Colostrum on Day of Calving	Milk 10 Days after Calving
K_2O	20.61	18.17	17.40	24.12
Na_2O	16.15	11.94	10.10	8.72
CaO	20 97	26.69	22.99	22.69
MgO	2.75	3 07	6.88	2.92
Fe_2O_3	0.19	0.05	0.42	trace
SO_3	3 74	3 94	2.82	4.10
P_2O_5	22 18	23 87	34.30	30.73
Cl	17 63	16.01	6.85	8.30

It is noticeable in the above tables that the phosphoric acid content is higher in colostrum and in the milk at the first stage of lactation, while the chlorine and sodium contents increase in the last stage of lactation. Salty milk, often found in the last stage of lactation, may be accounted for by these changes in salt content.

Schrodt and Hausen also made analyses of milk ashes, comparing stall feeding and pasturing. The results are given in the following table:

COMPOSITION OF MILK ASH ACCORDING TO THE METHODS OF FEEDING

	Stall Feeding				Pasturing				
	I	II	III	Average	I	II	III	IV	Average
K_2O	25.81	26.94	25.18	25.98	26 30	26.17	22.55	24.90	24.98
Na_2O	11.78	10 39	10 09	10 75	11.97	11 42	10.65	10.26	11.07
CaO	19 71	21.83	21.09	20 87	21 26	20 93	23.75	21.77	21.88
MgO	2 77	2 75	2.75	2 76	3 15	1 78	2.66	1.90	2.37
Fe_2O_3	0 13	0 21	0 05	0 13	0 08	0 11	trace	0 10	0 10
SO_3	4 07	4 15	3 75	3 99	4 38	4 20	3 29	4.30	4.20
P_2O_5	23.11	23 11	24 61	23 63	22.41	23 59	26 51	25.41	24.48
Cl	16.15	13 15	15 94	15.08	14.16	14.81	13 48	14.52	14.24

There does not seem to be much difference, in composition of ash, between the milk of stall-fed and pastured cows. Slightly more calcium and phosphoric acid are found in pastured milk. This may be due to pasturing, as it has been claimed by some authorities that the clover in the pasture influences the calcium content of milk.

There seems to be a slight difference in composition of ash according to the breeds of cattle. The ratio of CaO to P_2O_5 in milk ashes from different breeds is given as follows·

$\frac{CaO}{P_2O_5}$ RATIO OF MILK ASH FROM DIFFERENT BREEDS

Schlesish Red	1 : 1.42	Voitlander	1 : 1 26
Holstein	1 : 1 42	African Cross	1 : 1.26
Scheinfelder	1 : 1 39	Simmenthal	1 : 1.21
Korean	1 : 1.39	East Prussian Holstein	1 : 1.21
Brown Swiss	1 : 1 34	Ceylon	1 : 1.18
African	1 : 1 30	Reddish-brown Friesian	1 : 1.15
Wilstermarsh	1 : 1 28	Roman Cross	1 : 1 15
Black-spotted Friesian	1 : 1.28	Buffalo	1 : 1 02
Rumanian	1 : 1 28		

Diseases of cows have some effect on the composition of milk ash. Bögold and Stein analyzed the ash of so-called salty milk, with the following results:

COMPOSITION OF ASH OF SALTY MILK

	K_2O	Na_2O	CaO	MgO	P_2O_5	SO_3	Cl
Healthy milk......	20.59	13.02	21.55	2.72	26.42	3.66	15.58
Salty milk........	21 69	14 97	20.93	2.21	22.02	3.48	18.65
	10 96	33.17	11.70	2.16	15.63	6 73	25.23
	11.09	31 29	14.61	1.16	15.34	3.92	29.19

It is very noticeable that the contents of sodium and chlorine are strikingly greater in salty milk than in healthy milk. The saltiness of milk can, therefore, be accounted for very readily from these results. As already stated, at the later stage of lactation, milk sometimes develops a salty flavor; this may be accounted for by the increase in the sodium and chlorine contents of the milk ash. Schrodt analyzed a sample of milk ash from a cow about to dry up, and found a decided increase in both sodium and chlorine contents.

COMPOSITION OF MILK ASH FROM COW ABOUT TO DRY UP

K_2O	Na_2O	CaO	MgO	Fe_2O_3	SO_3	P_2O_5	Cl
8 52	40 85	8 04	1 82	0 97	5 68	9 70	24.35

Schrodt analyzed the ash of mastitis milk, which also showed increased sodium and chlorine contents.

COMPOSITION OF ASH FROM MASTITIS MILK

K_2O	Na_2O	CaO	MgO	Fe_2O_3	SO_3	P_2O_5	Cl
10 56	24.92	16 77	2 70	....	1.56	24 56	24.52

V. Storch analyzed milk ash from a cow suffering from udder tuberculosis, with the following results:

COMPOSITION OF ASH FROM SAMPLES OF TUBERCULAR MILK

	K_2O	Na_2O	CaO	MgO	Fe_2O_3	SO_3	P_2O_5	Cl
1.................	. .	.	10 91	.....	. ...	.....	15.67	
2...............	10 87	40 60	4 34	1 27	.....	5 08	7.10	
3............ ..	13 27	22 39	24.67	3 43	....	9 21	25.42	
4. Diseased gland.	5.08	42 37	.... .	0 79	......	.....	8.76	44.64
Healthy gland..	12 64	21 79	.....	2 10	.....	......	22.22	27.99

The increases in sodium and chlorine are very striking also with tubercular milk. G. Koestler compiled analyses of milk ash from healthy cows and from cows suffering with udder diseases.

Composition of Ash from Normal and Abnormal Milk

	CaO	K_2O	Na_2O	MgO	P_2O_5	SO_3	Cl
Average healthy milk	24.95	24.97	5.94	2.37	27.00	2.90	13.81
Salty milk from healthy cows	15.88	11 94	22.90	0.60	15.74	5.40	35.40
	14 82	14 53	22.86	1.68	17 61	6.97	28.55
	18 17	16 57	22.57	1.50	21 33	2.74	23.92
	11 56	17 04	17.08	.....	24 26	7 30	23.22
	7 44	8 94	36.54	1.74	17 38	1 34	33.63
Slimy udder catarrh	16.77	10 56	24 92	2.70	24.56	1.56	24.52
	8 04	8.52	45.85	1.82	9.70	5.68	24.35
Udder tuberculosis	8 70	7 00	55.00	1.00	10.00	.....	31.60
	7 52	5 08	42 37	0 79	8 76	....	44 64
	4 34	10 87	40.60	1.27	7.10	5.04	30.34
Udder disease (unspecified)	16 77	10.56	24.92	2.70	24 56	1.56	24 52
Blood serum of cattle	1 59	3 20	54 85	0.70	3.35	.....	46.87

Here again, milk ash from diseased udders invariably showed high contents of sodium and chlorine, which correspond with the blood serum of cattle, given for reference. It was stated in the discussion of pathological milk that the general composition of milk becomes very similar to that of blood serum in the worst cases of udder tuberculosis. The same is true of the composition of the ash. When the milk glands are attacked, they can no longer perform their natural function, and, as a consequence, the secretory process is changed to a filtration phenomenon. The secretion in such cases is not milk, but is, in a sense, a slightly modified blood serum.

As stated before, milk is secreted by mothers, primarily to feed their new-born young, and therefore it must include all the necessary nutrients in the most ideal proportions for the growth of the young. The materials for building bones can only be found in the

ash of milk. There must be a certain relation between the composition of the bone ash of the suckling and that of the milk ash of the mother. Bunge and Abderhalden analyzed the bone ash of sucklings of different mammals and the milk ash of the respective species. The results are as follows:

COMPOSITION OF BONE ASH AND MILK ASH

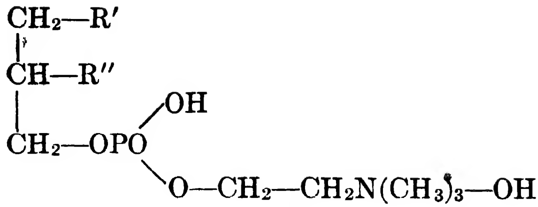
	Dog		Rabbit		Dolphin		Human	
	Suckling	Milk	Suckling	Milk	Suckling	Milk	Suckling	Milk
K_2O..	8.49	11 86	10 84	10 66	8.09	9.69	7.06	32.04
Na_2O..	8 21	5 75	5.96	7 92	6.79	9.00	7.67	13.10
CaO...	35 84	33 74	35.02	35 65	32 36	31.07	38.08	13.90
MgO.	1 61	1.57	2 19	2 20	3 44	3.10	1.43	1.90
Fe_2O_3..	0 34	0 12	0.23	0 08	0.28	0.17	0.94*	0.07
P_2O_5...	39.82	36 79	41.94	39 86	41.79	37.02	37.66	11.40
Cl.....	7 34	13.14	4.94	5.42	9.46	12.84	6.61	21.70

* $Fe_2O_3 + Al_2O_3$

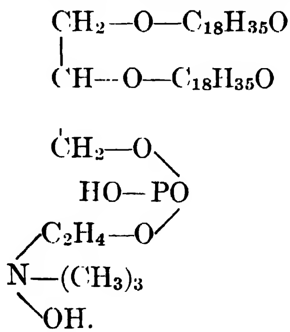
There is a close relationship between the ash contents of the suckling's bones and the ash of its mother's milk, except in the case of human milk. Of course, the mission of ash in milk is not only to supply materials for the building of bones in sucklings; it has many other functions in nutrition. Animals that rear their offspring in a short time must produce milk that contains more materials necessary to produce bones quickly, as in the case of the dog, rabbit, and dolphin, as given above. With animals that nurse their young for a long time, the case is different, and the plane of nutrition is consequently different.

LECITHIN; PHOSPHATIDS

Lecithin, $C_{44}H_{90}O_9NP$, is present in milk, though in very small quantity. In its structure lecithin resembles the fats, and it is mixed with them in milk. The foundation of lecithin is glycerophosphoric acid, $C_3H_5(OH)_2OPO_3H_2$; that is to say, two hydroxyl radicals of glycerin may be in combination with fatty acids, and the other hydroxyl radical is in combination with phosphoric acid, thus:



In the above formula, R′ and R″ are the radicals that are to combine with fatty acids. Therefore, there are possibilities of stearyl, palmityl, and oleyl-lecithins; but the one that is commonest and most studied is distearyl lecithin. Its formula is the one first presented, and its structural formula is as follows:



The presence of this distearyl lecithin in milk is recognized. According to Burow, oleo-butyro-lecithin is also present, being mixed with the other:

$$\begin{array}{l} CH_2\text{—}OOC\text{—}C_3H_7 \\ | \\ CH\text{—}OOC\text{—}C_{17}H_{33} \\ | \\ CH_2\text{—}OPO_2(OH)C_5H_{14}NO. \end{array}$$

According to Nerking and Hänsel, the lecithin content of different milks is as follows:

LECITHIN CONTENT OF MILK

	Maximum	Minimum	Average
Human	0 0799	0.0240	0 0494
Cow	0 1163	0.0364	0.0629
Ass	0 0393	0 0058	0.0165
Sheep	0 1672	0 0509	0 0833
Goat	0 0753	0.0364	0.0488
Mare	0.0174	0.0073	0.0109

According to the above table, the amount of lecithin is greatest in sheep's milk, and least in mare's milk. The amount in cow's milk is comparatively high. In all cases, however, the lecithin content is less than 0.1 per cent.

Vageler used alcohol instead of chloroform for the extraction of lecithin, and obtained higher figures than those obtained by Nerking and Hänsel. His results are as follows:

LECITHIN CONTENT OF MILK

(After Vageler)

	Phosphorus in Per Cent of Dry Matter	Lecithin in Per Cent of Dry Matter	Lecithin in Per Cent of Milk
Cow's milk...........	0.05534	1.444	0.173
Goat's milk..	0.05019	1.310	0.170
Ass's milk	0.04998	1.304	0.130
Sheep's milk	0.05857	1.528	0.260

Here again, sheep's milk contained more lecithin than that of any other animal. Otakar Laxa[22] called attention to the importance of studying phosphatids in the udder. He anticipated that they would be found to play an important rôle in the formation of milk and milk fat. He further stated that the udder is richer in materials of phosphatid nature than the milk. He found that the materials of cephaline nature are predominatingly phosphatid, and the substances of lecithin nature exist in much smaller quantities.

CHOLESTERINE

Tolmatscheff discovered the presence of cholesterine in human and cow's milk. The findings of Schmidt-Mühlheim, Bömer, Kirsten, Salkowski, and Menozzi proved the identity of milk cholesterine with that of bile. Its formula is $C_{27}H_{46}O + H_2O$, and the structural formula is

$$\begin{array}{c}(CH){=}CH{-}CH_2{-}CH_2{-}C_{17}H_{26}{-}CH{=}CH_2\\ \quad CH_2 \qquad CH_2\\ CHOH.\end{array}$$

[22] Proc., World's Dairy Congress, 1923, p. 1168.

Cholesterine is insoluble in water and is soluble with difficulty in petroleum ether and in cold alcohol. It is readily soluble in warm alcohol, and is soluble in ether, and in chloroform.

OTHER MINOR SUBSTANCES

Besides the substances discussed thus far, milk contains, according to Bouchardat and Quevenne, about 0.01 per cent of urea. According to Schmidt-Mülhheim, the urea content of cow's milk varies from 0.0079 to 0.0103 per cent. Schöndorf found in human milk 0.0484 per cent on an average. Earlier investigators reported the presence of creatin, creatinin, xanthin, and hypoxanthin in milk, but the amount is not shown. According to Duval, there is present in neutral mare's milk a certain salt which, upon being heated, gives out a peculiar odor. Duval named this substance *acide équinique.* Musso says that sulphocyanate may be present in milk. He calculated its presence from 0.00021 to 0.00046 per cent as potassium sulphocyanate. Biscow and Belloni obtained flaky crystals by evaporation of lactose factory whey. Upon purifying the substance, they found that it had the formula $C_5H_4N_2O_4$. If this is oxidized with permanganate, it produces urea. They named this substance *oritic acid,*

W. Denis, F. B. Talbot, and A. S. Minot found that the non-protein nitrogen of human milk is not very variable during the day, but that the quantity present is not always the same. They analyzed seventy-one samples for the non-protein nitrogen and found the following variations.

NON-PROTEIN NITROGEN OF MILK

	Quantity per 100 Cc. Milk	
	Maximum	Minimum
Total non-protein nitrogen	20.0 mg.	37.0 mg.
Urea nitrogen	8 3	16.0
Amino nitrogen	3 0	8.9
Preformed creatinin	1 0	1.6
Creatin	1 9	3.9
Uric acid	1 7	4 4

Of the above, urea, preformed creatinin, and uric acid are present in about the same proportion as in blood. The percentage of amino acid is also about the same as in blood, but some-

times it is lower in milk. The amount of creatinin is much less in milk than in blood.

GAS

When drawn from the cow, milk already contains gas. It also absorbs gas from the air during the process of milking. Hoppe-Seyler studied the subject as long ago as 1860, and found that milk contains 0.16 per cent, by volume, of gas. According to Winter Blyth, the composition of gases in milk is as follows:

Composition of Gases in Milk
(Cubic Centimeters per 1000 Cc. of Milk)

	Fresh Milk	Milk after Standing 2 Hours
Carbon dioxide	0 06	60 47
Oxygen ..	19 13	9 30
Nitrogen	77 60	30 21

It may be noticed that on standing the composition of the gases in milk changes a good deal. Nitrogen and oxygen diminish, and carbon dioxide increases very pronouncedly. Blyth states that when milk has stood for twenty-four hours, the oxygen has usually disappeared and the carbon dioxide increased. About 95 per cent of the total gas in milk finally becomes carbon dioxide, the remainder being nitrogen.

Külz analyzed the gases in human milk, with the following results.

Composition of Gases in Human Milk
(Cubic Centimeters of Gas per 100 Cc. of Milk)

	O	CO_2	N	Total Gas
I.	1.25 cc.	2 87 cc.	3 47 cc	7.49 cc.
II.	1 44	2 35	3 81	7.60
III.	1.07	2 40	3.62	7 09
IV.	1.38	2.63	3 52	7 53
V.	1.23	2.74	3.39	7.36

The amount of carbon dioxide in milk has been the subject of several investigations. A recent study of the subject was made by Van Slyke and Baker. According to their findings, in twenty-

five samples of milk, drawn from separate quarters of the udder, the carbon dioxide varied from 7 per cent by volume to 86. They also found that the *p*H value generally varied with the CO_2 content. They state that the CO_2 content of normal milk is about 10 per cent by volume. The amount of carbon dioxide in milk, as reported by them, is as follows:

AMOUNT OF CO_2 IN COW'S MILK

Per Cent of CO_2 by Volume	*p*H Value	Cc. of 0.1 N Alkali Required to Neutralize 100 Cc. of Milk	Per Cent of CO_2 by Volume	*p*H Value	Cc. of 0.1N Alkali Required to Neutralize 100 Cc. of Milk
8	6 50	19 1	9	6 62	17.2
7	6 52	20 0	10	6 63	18.0
8	6 53	18 0	10	6 65	16 6
10	6.54	16 0	12	6 70	15.4
10	6.55	17 2	12	6 80	16.0
8	6 55	18 4	18	6.82	13.0
11	6 57	17 2	14	6.86	14 0
10	6 58	17 8	22	6 90	12 0
10	6 58	16 9	33	6 92	12 0
10	6 58	18 4	24	7 00	10.0
9	6 60	18 2	56	7 05	6 0
10	6.61	16 8	86	7.16	4.0
10	6.62	17.8			

According to the above table, the content of carbon dioxide varies a good deal. It is noticeable that, while the *p*H value apparently increases with the increase in carbon dioxide, the apparent acidity, as titrated with alkali as in the usual method, decreases with the increase of carbon dioxide. Formerly, the apparent acidity of fresh milk was attributed partly at least to the presence of carbon dioxide. The results obtained by Van Slyke and Baker disprove this. The apparently high *p*H value with higher CO_2 content must be rather incidental, for by exhaustion of CO_2 from milk the *p*H value increases.

As to the form in which CO_2 exists in milk, Van Slyke and Baker make the following statement: It has been generally assumed that CO_2 exists in milk as uncombined carbonic acid. From the fact that the reaction of milk is less acid than that given

by a corresponding solution of CO_2 in water, it appears probable that the CO_2 in milk is present in part as carbonic acid and in part as bicarbonate.

ENZYMES

There are many kinds of enzymes in milk, but they do not seem to have any special functions. They are simply body enzymes and appear in the milk rather accidentally, having come through the blood. Among them, however, are found many useful enzymes which serve directly or indirectly for the manufacture of some of the dairy products and for the testing of milk for quality. The enzymes in milk may be divided into three general classes, namely, hydrolyzers, oxidizers, and catalyzers.

Galactase.—Among the hydrolyzing enzymes, there are protein hydrolyzers, starch hydrolyzers, and fat hydrolyzers. The protein-hydrolyzing enzyme was first discovered in milk by Babcock and Russel, in 1897, and was named, by the discoverers, galactase. In the course of a study on the ripening of cheese, they preserved milk with preservatives in order to suppress bacterial growth in the sample. After eight months of preservation they discovered that the protein of the milk was dissolved. They precipitated the protein of the samples with acetic acid, and found that there were from 25 to 75 per cent of non-precipitable protein-cleavage products. Later, they found that this enzyme is abundant in separator slime. Wender reported that other enzymes besides galactase are present in separator slime, including peroxydases and catalases. The action of galactase resembles that of trypsin; it produces first proteoses and peptones as intermediate products, and finally amino acids as end-products. This enzyme is also found in buffalo's, sheep's, goat's, mare's, ass's, and human milk. It is most active at temperature from 37° C. to 42° C. under alkaline reaction, but its action is much retarded under neutral or acid reaction.

Amylolytic Enzyme.—The appearance of an amylolytic enzyme in milk has already been proved. Béchamp found it in human milk as early as the year 1883, but he stated that he could not find it in cow's milk. Spolverini and Muro confirmed the discovery of Béchamp. Spolverini found this enzyme not only in human

milk but also in dog's and in ass's milk. Zaitschek and Race later found that amylase is also present in cow's milk, and suggested that this enzyme may find its way into the milk from feeds.

Glycotic Enzyme.—A glycotic enzyme, which hydrolyzes sugar, was first discovered in 1902 by Spolverini in cow's, goat's, human, dog's, and ass's milk.

Lipase.—Nuro and Hippius discovered the presence of an enzyme that hydrolyzes the fat. Muro found that olive oil was saponified in cow's and human milk. Hippius reported that almond oil was hydrolyzed in human milk. Marfan and Gillet do not admit the presence of an enzyme that hydrolyzes triolein, but do admit the presence of monobutyrase in cow's and human milk. Luzzati, Biolchini, and Spolverini also proved the presence of monobutyrase in human, cow's, goat's, ass's, and dog's milk.

Besides the enzymes mentioned above, the so-called salolase, which hydrolyzes phenyl salicylate, is also said to be present in cow's and ass's milk, by Nobécourt and Merklen; but Mule and Willem do not accept their findings.

Oxydases.—The author, working with H_2O_2 as a preservative, found that milk develops a rancid flavor when H_2O_2 is added to it. This is due to the presence of an oxydase. This enzyme is very unstable, and upon heating to 140° F., or 60° C., it loses its activity. This principle may be applied in detecting the heating of milk, by testing the degree of activity of this enzyme. When milk is heated as high as 176° F., or 80° C., the enzyme is almost totally destroyed. In order to detect the pasteurizing temperature, a sample of milk is taken into a test tube, and a drop of 2 per cent solution of H_2O_2 and 2 drops of 2 per cent paraphenylendiamin solution are added. The mixture is shaken. If the sample is a raw milk, the color is immediately changed to violet. If the milk has been heated to a very high temperature, the color will not change. The intensity of the color developed depends upon the degree of heat that has been applied to the milk. In place of paraphenylendiamin, guaiacum tincture may be used. In this case the color that appears will be a deep blue for raw milk.

Peroxydases.—Peroxydases are more important than oxydases. The presence of peroxydase in milk is also applied in detecting the nature of the milk, as in the case of oxydase. The reagents used for the detection of heated milk in this case are

exactly the same as in the previous case. Peroxydases are abundantly present in cow's, mare's, sheep's, goat's, human, dog's, ass's, and rabbit's milk.

Catalase.—Catalase decomposes H_2O_2 into water and the oxygen molecule,

$$2H_2O_2 = 2H_2O + O_2.$$

The author, while he was working with H_2O_2 as a preservative of milk, also found that when H_2O_2 is added to milk innumerable small gas bubbles are evolved. They are the oxygen gas produced by the decomposition of H_2O_2 by catalase. The difference between the action of catalase and that of peroxydases is that the latter take atomic oxygen out of H_2O_2:

$$H_2O_2 = H_2O + O.$$

The oxygen thus obtained is nascent oxygen and combines very readily with the constituents of the milk, forming no gas. The action of catalase on hydrogen peroxide is entirely different. The oxygen produced by catalase is comparatively inactive. Catalase is sometimes included among the reductases, but some hold the opinion that it should not be so included.

Reductases.—Enzymes that abstract oxygen from certain substances without forming oxygen gas are called reductases. The chief difference between reductase and catalase is that in the case of the former the abstracted oxygen is utilized at once. Reductases are divided into two groups according to their action toward methylene blue. One is of cellular origin, and is present in fresh milk. This reductase reduces the methylene blue very quickly in the presence of a trace of formaldehyde in milk. The other is of bacterial origin and reduces methylene blue in the absence of formaldehyde. Therefore, the latter is employed in determining the freshness of milk.

One gram of methylene blue is dissolved in 500 cc. of water and called the stock solution. In applying the test, 1 cc. of this stock solution is diluted with 39 cc. water, and 1 cc. of this diluted methylene blue solution is added to 10 cc. of the milk to be tested. By the degree to which the color fades or disappears, and by the time required, the degree of freshness of the milk may be ascertained. In Europe, it is considered that the milk is unwholesome

if the color disappears within twenty minutes. In such a case, the bacterial content is said to be more than 20,000,000 per cubic centimeter. When the mixture is decolorized in from twenty minutes to one hour, the number of bacteria may vary from 4,000,000 to 20,000,000 per cubic centimeter. When the time required for decolorizing is between two and five hours, the bacterial number may be from 500,000 to 4,000,000 per cubic centimeter. If the original color is retained for more than five hours, the milk is said to be perfectly fresh and to contain less than 500,000 bacteria per cubic centimeter.

The strength of the methylene blue solution to be used for this test is variously given by different authors. For instance, Fred used 1 part of crystallized methylene blue to 20 000 parts of milk. Jones recommended 1 : 50,000. Müller used 1 : 40,000. Kufferath employed 1 : 3000 to 4000. Simmons proposed 1 : 10,000. Hastings and his co-workers conducted some investigations on this point and found that the strength of the methylene blue has a considerable influence on the time of decolorizing. When strong methylene blue solution is added to a given amount of milk, the time of decolorization is prolonged, and *vice versa*. They attribute this prolongation of reduction time to a certain disinfectant property of methylene blue.

Certain authors insist on using fresh solution and others on using sterile solution. Hastings and his co-workers found that there was not much difference in the results with old and with fresh solutions. Therefore, they recommend making a stock solution of methylene blue, in order to minimize the trouble of making the test.

The temperature at which the tests are made has a considerable influence upon the time of reduction. Rahn and Arup found that the reduction took place more quickly at 30° C. than at 38° C.; but Hastings and his co-workers found that at lower temperatures a longer time was required for reduction. At 28° C. it took about twice as long as at 38° C.; and at 33° C. it took about 50 per cent longer than at 38° C. The usual temperature at which the reduction tests are made is from 37° C. to 38° C.

At first it was thought that certain bacteria did not reduce methylene blue; but, according to Hastings and his co-workers, all bacteria have the power of doing so. It is said that the

apparent inactivity of certain bacteria toward methylene blue is due to the retardation of their growth in milk on account of media and temperature.

As stated at first, the methylene blue reduction test is based upon the reductase produced by bacteria in milk. Hastings and his co-workers, however, express their opinion that the reduction may be attributed to direct bacterial action rather than to the enzyme produced by bacteria. To support this opinion they state that when milk is heated the reduction of methylene blue is greatly retarded, and this retardation also takes place when the temperature is such that the bacteria are killed but the enzyme is not destroyed. Until it is possible to prove the presence of the enzyme after heating, this statement is acceptable only as a suggestion. These workers, however, present some evidences in support of the statement. They added boric acid to milk in the proportion of 1 : 2500, with the result that the reduction time was doubled. They also take into consideration the retardation of reduction by using stronger methylene blue, which exhibits a certain disinfecting power.

Müller found, in 1906, that milk that originally fermented and produced a certain degree of acidity does not retard the reduction after it has been neutralized. Orla-Jensen's findings also prove this.

The relation between the reduction test and the bacterial content of milk has been the subject of much study. It is claimed by most investigators that there is a close relation between the result of this test and the general quality of the milk, and also that this test gives a better and truer idea of the number of bacteria in the milk than plating out. It is also easier and quicker than the ordinary plate method. For these reasons, this test is recommended for testing at the receiving platform. In fact, many up-to-date cheese, condensed-milk, and butter factories, as well as city milk plants, are adopting this method in grading milk.

IMMUNIZING BODIES

If antibodies are present in the mother's blood, some of them appear in the milk; the suckling thus receives antibodies from the mother and becomes immune to the disease against which the

antibodies are a protection. Of course, the amount present in milk is much less than that in the blood.

Agglutinins and precipitins are also carried from the blood to the milk. The amount appearing in the milk is usually about the same as in the blood. Amboceptors and complements are sometimes carried into the milk from the blood; but their occurrence is rather rare, especially the occurence of both at the same time. The presence of complements in milk is much questioned; but it is said that in colostrum from a mastitis udder amboceptors and complements are both found.

So-called opsonins, the bacterin for phagocytosis, are also said to be present in milk. When the remedy known as "606" is injected into a suckling mother, it is said to affect the offspring. The reason for this is not clear; it may be due to the transmigration of antibodies to the milk from the blood, or to that of arsenic.

If the transmigration of antibodies into the milk from the blood is accepted, the transmigration of aggressin and toxins must also be accepted. Some experimental evidence shows such migration.

As milk contains many proteins, antigens may also be present. Therefore, by injection, various antibodies may be produced. Lactoserum obtained from milk shows the presence of precipitins, amboceptors, and hæmolysins, and these are specific in their reaction. Therefore, by the application of this principle, the quality of the milk can be ascertained. By employing this method, Bauer was able to detect the presence of cow's milk in human milk in the proportion of only 1 cc. to 1 liter.

VITAMINS

"Vitamin" is the most popular word known, not only among nutrition investigators, but also among all who are concerned with food. It is the name given by Funk in 1911 to a certain substance which cures neuritis of doves. Since then the word has been used very freely, and investigation in this field has made tremendous progress. The so-called vitamin of Funk was found in milk. Hopkins, however, called this substance, whose nature is unknown but which is very essential to health, an "accessory factor." McCollum found that there are two

unknown substances in milk that are essential to the growth of animals, one being soluble in milk fat and the other in water. He first opposed the use of the word " vitamin," proposing " fat-soluble A " and " water-soluble B." He found that the fats of milk, eggs, and animal organs contain considerable " fat-soluble A," but that in many foods it is either deficient or entirely lacking. "Water-soluble B " was found by the same author to be more widely distributed. Later, he found in orange juice an unknown basic substance which is also essential in the maintenance of health, and which he called " water-soluble C." While there have been disputes among scientists about the use of the word " vitamin " for these mysterious substances, which are all essential for growth and the maintenance of good health, the word is so freely used that it has almost become established. It is used to represent all of the three unknown substances, which are now designated as vitamins A, B, and C. Though not generally accepted, a fourth vitamin has been reported.

The investigations on vitamins being conducted at present are almost innumerable, and in many cases premature reports have been made. Therefore, there are many conflicting results, which will be explained as the investigations progress. No one now doubts the existence of vitamins or their importance in nutrition; but Hart has recently found that the presence of vitamins alone is not enough. Sunshine is a most essential factor in promoting the growth of chickens, together with vitamin A. Many of the conflicting results obtained may be due to negligence of some such factor as this.

Vitamin A, which is abundantly present in milk and milk products, is not only essential for the growth of the body, but is also necessary, according to Mellanby, to the growth of the teeth. Steenbock suggested that vitamin A may be particularly associated with the yellow pigment of butter, vegetables, and foodstuffs in general. It is now generally known that the vitamin content of milk varies, and this variation is due to many factors. The food given to cows has a great influence on the vitamin content of their milk. When vitamin-rich foods are given to cows, the milk naturally becomes rich in vitamins. Summer milk is said to contain more vitamins than winter milk, because in most cases cows are pastured on vitamin-rich green grass in the sum-

mer time, while in winter they are usually fed on hay and grains which are deficient in vitamins.

It is often said that heating milk destroys some of the vitamins, but experiments do not verify this statement. Recent studies indicate that milk may be heated to the pastuerizing temperature in the absence of air, with little, if any, vitamin destruction. It is even said that milk may be boiled for a short time with less vitamin destruction than if it were heated for a long period at a lower temperature.

Many investigators have demonstrated that vitamin A is quite susceptible to oxidation while vitamin B is apparently quite stable. Vitamin C is readily destroyed by oxidation, although the ordinary method of vat pasteurization is not considered to be very destructive.

As to the vitamins in preserved milk, Dr. Kennedy [23] reported at the World's Dairy Congress, held in America, in 1923. An abstract of her report follows:

> The vitamin content of condensed milk has not been as thoroughly studied as that of other preserved milks, and many of the statements in the literature in regard to this question appear to be generalizations rather than results of actual experiments. Hess and also Hume state that sweetened condensed milk retains practically all of its vitamin C. Daniels and Laughlin show that purified rations, to which either unsweetened evaporated milk or sweetened condensed milk was added to supply vitamins A and B, are adequate to support animal growth.
>
> The vitamin content of dried milk has been much more carefully studied, and fairly definite conclusions can be drawn, although the work has not always been carried out under ideal conditions. Such conditions would be the planning of feeding experiments so that the same milk could be fed both in the fresh condition and in the dried form. A very satisfactory substitute for this method was used in this laboratory in comparative tests of spray- and. drum-processed dried milks, by extending the feeding experiments over a period of a year, so that any differences in the vitamin content of the milk due to seasonal changes in the food of the cow could be explained as such and not wrongly attributed to the process used in drying. From experiments thus carried out, data were obtained which, it is believed, show more exactly the effects of drying processes on vitamins A and B than any previously obtained. It was

[23] Proc., World's Dairy Congress, 1923, p. 198.

found that the growth-promoting vitamin B is not affected either by the spray or the drum process of drying; that the vitamin-A content of drum-dried milk more nearly approximates that of the original milk than does that of milk dried by the spray process; and that in both kinds of dried milk a change in the vitamin content, corresponding to changes found in fresh milk due to seasonal changes in the feed of the cow, may be expected.

Milk powders vary in their content of vitamin C, the antiscorbutic factor, not only because fresh milk varies in its vitamin content but also because the experiments so far published show that one process of drying is more destructive to this vitamin than another. Thus it has been repeatedly shown that the drum process of drying, which minimizes the period of exposure to heat and oxidation, does not destroy vitamin C to so great an extent as does the spray process. Although it has never been shown that drum drying has no destructive effect on this factor, it has been found that milk so processed still contains enough of its antiscorbutic properties to protect babies and experimental animals from scurvy.

While experimental animals are very valuable in determining the biological value of foods with respect to certain constituents, the results so obtained cannot be directly applied to children because of the great differences in the rate of growth. Therefore, actual feeding tests have been made with young children to determine whether dried milk can satisfactorily replace fresh milk in their dietaries. The results of several workers show that the growth curves of children fed exclusively on dried milk closely resemble those of breast-fed children, and that there is no greater tendency in infants so fed to develop rickets and scurvy than in infants fed on fresh cow's milk.

According to the above statement, the spray method of drying milk is more destructive than the drum process. Cavannough found that when milk is condensed in vacuum before spraying, the destruction of vitamins can be prevented. Dutcher reported at the World's Dairy Congress that when dried milk is prepared by evaporating in vacuum, atomizing under high pressure, and drying instantaneously, the spray powder has a vitamin content equal to that of the drum-dried powder. The work of the United States Department of Agriculture has shown that vitamins A and B are not destroyed by any of the drying processes.

MILK AS A STANDARD OF NUTRITION

As already stated, milk contains all the necessary nutrients, and its composition is more nearly balanced than that of any other food. It is an ideal food for growing animals as well as for human beings. It is therefore taken as a standard of nutrition. When milk is given to growing children, their growth is greatly promoted. This fact has been repeatedly proved by experiments. Thomas showed, in the year 1909, that the amount of protein required to prevent the diminution of body tissue varies with the kinds of protein supplied in food. From the results obtained by comparative tests of proteins from different foodstuffs, he calculated what he called "biologic value." In this calculation, he took milk protein as the standard, giving it a value of 100. The "biologic values" of different foodstuffs are as follows:

Biologic Values of Foodstuffs

Milk	100	Yeast	71
Beef	104	Casein	70
Fish	95	Peas	56
Rice	88	Wheat flour	40
Potatoes	79	Corn meal	30

The above figures are widely used at present, but it is said that they are not entirely reliable. Later, McCollum calculated the minimum requirement of protein for the maintenance of body weight for different foods.

Minimum Requirement of Protein for the Maintenance of Body Weight

(Plane of Protein Necessary for Maintenance)

Source of Protein	Per Cent of Foods
Milk	3.0
Oats	4.5
Millet	4.5
Corn	6.0
Wheat	6.0
Polished rice	8.0
Beans	12 0
Peas	12.0

Hart and Humphrey investigated the efficiency of various proteins in the production of milk. They found that the proteins of milk, oil meal, and distiller's grains are most efficient. The results given by them are as follows:

EFFICIENCY OF VARIOUS PROTEINS FOR MILK PRODUCTION

	Per Cent		Per Cent
Milk	60	Oil meal	61
Distiller's grains	60	Gluten feed	45
Corn	40	Wheat	36

Clemens Pirquet [24] reported, at the World's Dairy Congress, in 1923, on milk as a standard of nutrition, explaining his "nem" value. He made the following statement, in brief:

1. A "nem" is the nutritive, combustible value of 1 gram of average human milk. The name is composed of the initials of the words "Nahrungs-Einheit-Milch," or "Nutrition Equivalent Milk," and refers to a standard human milk of 1.7 per cent of protein, 3.7 per cent of fat, and 6.7 per cent of milk sugar, as well as to a standard cow's milk of 3.3 per cent of protein, 3.7 per cent of fat, and 5 per cent of milk sugar.

2. In spite of the great variations in the content of solids in the milk, we are entitled to take a certain theoretical average as a standard, just as we use the horse-power as a standard for our machines, disregarding the fact that every individual horse has a different power.

3. The standard milk chosen has a simple relation to the calorie system, having 667 small available calories in 1 gram, or 667 large calories in 1 kg.; 2000 small calories equal 3 nems, or 1 large calorie equals 1.5 nems.

4. This milk unit is used as a metric unit, and is combined with the Latin prefixes for metric fractions, and with the Greek prefixes for multiples of the unit.

A decinem means one-tenth of a nem, or the nutritive value of 1 decigram of milk, 0.1 gram, and is written 1 dn. A centinem is written 1 cn., and represents 0.01 gram.

These smaller units are used only in the calculation of food intake per square centimeter in relation to the nutritional surface.

In the practical use of foodstuffs we have to make use of the larger units, namely, the multiples with Greek prefixes: A dekanem (Dn.) means 10 nems; a hektonem (Hn.) means 100 nems. This unit is used in the composition of a recipe for a certain

[24] Proc., World's Dairy Congress, 1923, p. 463.

dish, or of the day's program for one person or family. A kilonem (Kn.) means 1000 nems. We use it in buying foodstuffs for a family, or in making recipes for a large number of people. A tonnenem (Tn.), finally, represents the food value of 1 metric ton of milk, 1000 Kn. or 1,000,000 nems. We use it in community nutrition.

5. The food values of all articles used for human food should be determined by substituting a given quantity of the article for milk. In the meantime, we use a chemical analysis of the food, discount the percentage of combustibles lost in the urine and in the feces, and translate grams and calories into nems.

The nem values calculated by this author for some of the most important foodstuffs are given in the following table, which gives at the same time the weight of 1 hektonem in grams. If 1 gram of flour has a food value of 5 nems, 20 grams will contain 100 nems, or 1 hektonem. The " hektonem weight " of flour, therefore, is 20.

NEM VALUES OF SOME OF THE MOST IMPORTANT FOODSTUFFS

Nems in 1 Gram	Foodstuffs	Hektonem Weight
13.5	Pure fat, oil	7 5
12.0	Butter	8.5
13.0	Bacon	10 0
6.0	Sugar, cocoa	16 7
5.0	Wheat flour, oat flour, biscuit, rice, ham, fresh fat meat, cheese, syrup, honey	20.0
4.0	White bread	25.0
3.5	Dark bread	30.0
2.5	Fresh meat, eggs	40.0
1.25	Potatoes	80.0
1.0	Milk, green peas	100.0
0.67	Fresh fruit	150.0
0.5	Skimmed milk	200.0
0.4	Turnip, spinach, cabbage, cauliflower, fresh mushrooms	250.0
0.2	Lettuce, cucumbers	500.0

CHAPTER III

TECHNOLOGY

If one wishes to master any manufacturing process, books cannot take the place of practice, but can only supplement it. Some things that are easy to do are hard to describe, and in some cases the reverse is true. This chapter is intended to explain, so far as may be, the principles involved in condensery practice.

THE RECEIVING PLATFORM

First-grade condensed milk cannot be made from poor milk. The man at the receiving platform has in his hands the key to the success or failure of the business. He must be not only an expert in judging the quality of milk, but also a diplomat. He is likely to be in closer touch with patrons than anyone else in the factory, and he often has to deal with delicate questions.

The milk coming to the receiving platform must be examined as to its flavor,[1] temperature, acidity, lactometer reading, alcohol test, etc. The fat test should be applied once in a week or ten days and whenever needed. The reduction test may also be applied in grading milk. If circumstances permit, bacteriological examination is also very useful. Not all of these tests can be made at the receiving platform, however, although samples for the tests must be taken. Most experienced receivers can tell the quality of milk by means of its smell and taste. The author served at the receiving platform of a condensery for a considerable time, receiving hundreds of cans of milk every day. With this experience, he could detect adulterated milk from the first smell when the lid of a can was taken off. The richness of milk can be judged fairly well without drinking, simply by placing a drop on the tongue, or, with long experience, simply by smelling.

[1] The milk specialist uses the word "flavor" to denote a quality perceived chiefly by the nose.

Pure fresh milk has a characteristic aroma. Many gradations in the intensity of this aroma may be detected, varying with the richness of the milk. The author often detected water-adulterated milk by smell. In one instance, when the lid was taken off, the milk had no wrong flavor, but the intensity of the characteristic milk flavor was not great enough. The thought at once occurred that the milk had been diluted with water, and a sample was taken for rigid physical and chemical tests. These showed

Courtesy of Molkerei, Zürich.

FIG. 20.—MILK RECEIVING ROOM.

the adulteration. After a confidential talk, the patron who had supplied the milk confessed the offense.

Under ordinary circumstances and with experienced receivers, the senses of smell and taste afford a very reliable means of grading milk. This method of grading is the quickest, hence the most practical, and is employed to a great extent in most factories. Even with the most experienced receiver, however, mistakes are liable to be made. The senses are not always reliable; they may be out of order. They should always be supplemented by chem-

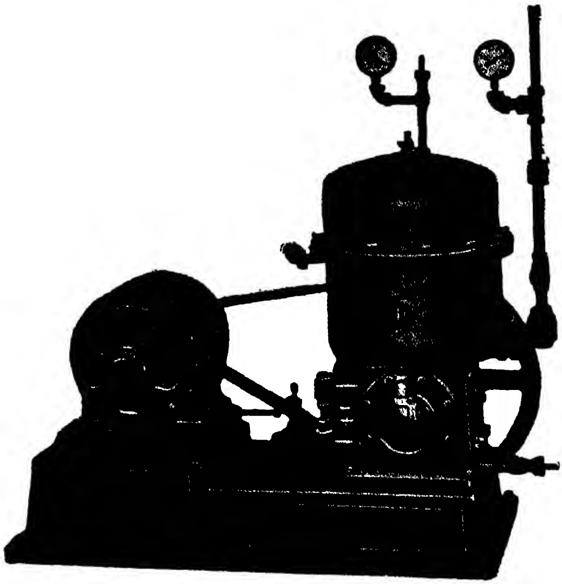
ical and physical tests. Of the many good methods, not all are useful at the receiving platform. To be practical there, a method must be capable of being worked quickly, simply, and cheaply, and must give immediate and fairly accurate results. Such tests are not many. Even the Babcock and Gerber fat tests are not for the platform; they must be performed in the laboratory. The methylene blue reduction test for bacterial content is very valuable, but it cannot be used for the immediate grading of milk at the platform, because even the poorest milk takes several minutes for results, and some samples take hours. This method also belongs to the laboratory.

The supplementary tests for use at the platform may include lactometer reading, temperature, alcohol, and acidity tests. The temperature of milk when received at the platform gives an idea of the care exercised by the dairyman, and shows how well he understands his business. At the same time it serves for the classification of the milk in the vat room. The lactometer reading is quickly and easily taken, and gives a fair idea of the quality of the milk. To be sure, this reading alone does not prove adulteration; it may raise suspicion, and in this case the suspected milk should be taken at once to the laboratory for further test before final decision is made.

The alcohol test is very useful as an indication of the wholesomeness of milk. Milk that is slightly fermented and pathological milk, both of which are quite unsuitable for the making of condensed milk, may be detected by this test. Sometimes perfectly fresh and wholesome milk gives a positive alcohol reaction, because of abnormal ash content. This case has been discussed in the section on coagulation.

The acidity test was formerly used as the sole test for determining the freshness of milk, any sample showing high acidity being condemned as having deteriorated. Fermented milk shows high acidity, but within certain limits acidity tests may be misleading. The fallacy of basing the deterioration test entirely on the acidity of milk has been discussed at length under the section on acidity of milk. It should be used as a supplement to the alcohol test for detecting deterioration, and to the lactometer reading for detecting water adulteration. If milk shows high acidity, and also coagulates with alcohol, it may be con-

demned as deteriorated. But a comparatively high acidity, say 0.2 per cent or thereabouts, should not condemn milk whose alcohol test is negative. Such milk in most cases is very rich milk, which should rather be welcomed. A very low lactometer reading, coupled with low acidity, is an almost sure sign of watered milk. These tests are all very simple, and are good methods for grading milk at the receiving platform, if properly applied and justly interpreted.



Courtesy of the Creamery Package Manufacturing Co., Chicago.

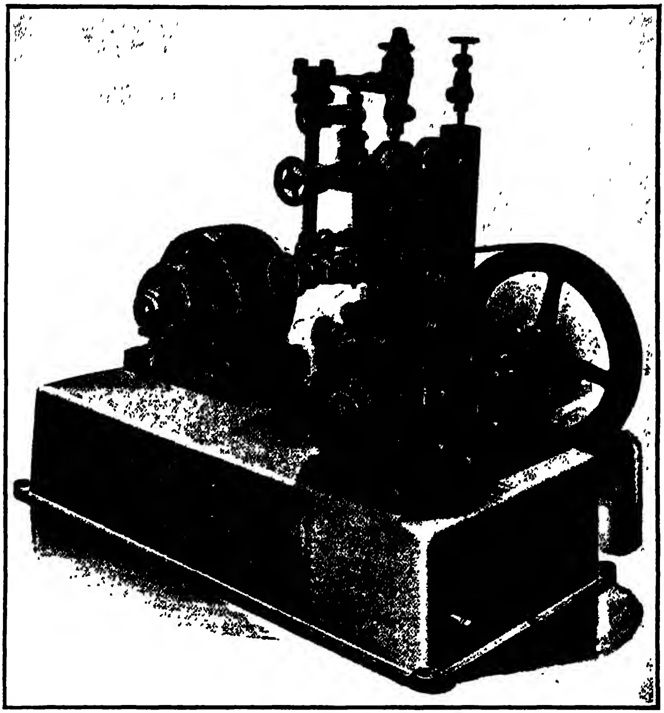
FIG. 21.—HOME REFRIGERATOR.

This is another small refrigerating machine adapted for home use. It requires only one-half horse power to run it.

A suggested routine for the receiving of milk at the platform is as follows:

1. Each can of milk brought to the platform should first be examined as to its flavor. This examination should be made by an expert. Care should always be taken that the lids of cans be not removed before the inspector is ready to examine them. He should open each can himself, test the flavor, and immediately classify the milk according to his judgment. Any suspected cans should be set aside for further examination.

2. The temperature should next be taken. This may be done by an assistant. If there are enough weighing cans and milk vats for classified milk, the can should be classified according to temperature, so that immediate attention may be given to cooling the warmer milk. It would be well to have several temperature classes, but it is hardly practicable to make more

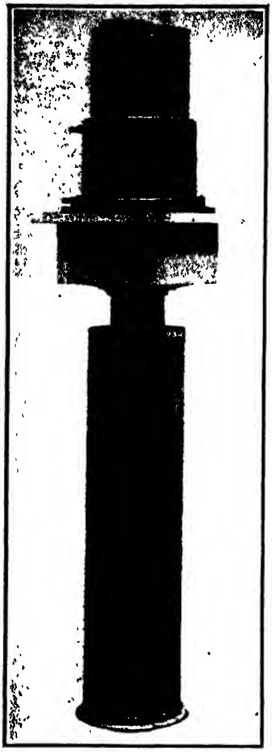


Courtesy of the Creamery Package Manufacturing Co., Chicago.

FIG. 22.—SMALL REFRIGERATING MACHINE.

This type of refrigerator may be conveniently installed for milk stations. Its capacity is 1½ tons of ice per day.

than two, one class for cans above 60° F. (15° C.) and one for those below 60°. If warm milk is mixed with cold, and is then held for some time before being cooled or processed for manufacture, an entire vat of milk may deteriorate, especially in summer time. It is the best policy to have a different weighing can and vat for the warmer milk, with a brine cooling system in the vat, or to let the milk run over a brine cooler directly after weighing.



Courtesy of Escher, Wyss and Co., Zürich, Switzerland.

FIG. 23.—AUTOFRIGOR.

Cooling is essential in handling milk. Where plenty of cold running water is available, the milk can be cooled readily and cheaply. Natural ice stored for summer use serves well. Where these are lacking, however, milk may be handled with success by the use of some sort of cooling machine. The "autofrigor" is made in sizes from 500 to 3000 calories per hour. Running expenses are confined to the little electricity used and the cost of the cooling water. There is no danger of leakage and little attention is required.

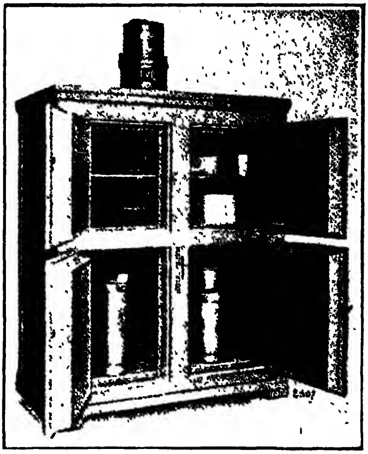
3. The alcohol test is now applied to each can of milk, and the cans are divided on this basis into positive and negative classes. The positive class is set aside for further test and should go for separation of cream. Only the negative class should enter the channel for manufacture into condensed milk. A careful assistant can perform this test very satisfactorily.

4. The milk cans placed in the negative class are now weighed. They may be carried to the weighing platform and the milk weighed on a platform scale or other device. It is best to weigh by emptying into weighing cans whose weight is known and counterbalanced. This weighing must be done very exactly. Many difficulties between the factory and its patrons arise from this point. This position requires a very accurate and conscientious worker. The scales should be examined each day for accuracy and sensitiveness before and after the milk is received. Rapid as well as accurate work is important at this stage.

5. When the milk is poured into the weighing can, a sample is taken for acidity, lactometer reading, fat test, reduction test, etc. The acidity test may be carried out on the platform by a trained assistant. Usually, N/10 NaOH solution is used for this test. If the acidity is higher than 0.18 per cent, the tester must give further attention to the milk. If it is higher than 0.20, the chief inspector should be consulted; and if higher than 0.23, the

milk may be condemned. If the acidity is lower than 0.15, further examination is advisable. If the figure is below 0.13, the chief inspector should be called; and if below 0.10, the milk may be rejected.

Lactometer readings may be made at the temperature of the milk when received, and corrections made for temperature from a table posted on the platform. Accurate work is required here also; but it must keep step with other operations, and therefore it must be done quickly. If the lactometer reading is above 35°, the sample should be sent to the laboratory for further examination. In such a case there is a suspicion either of skimming or of addition of colostrum milk. If, on the other hand, the lactometer reading is below 28°, there is a suspicion of watering or of naturally poor milk. Samples of such milk should also go to the laboratory for further examination.



Courtesy of Escher, Wyss and Co., Zürich, Switzerland.

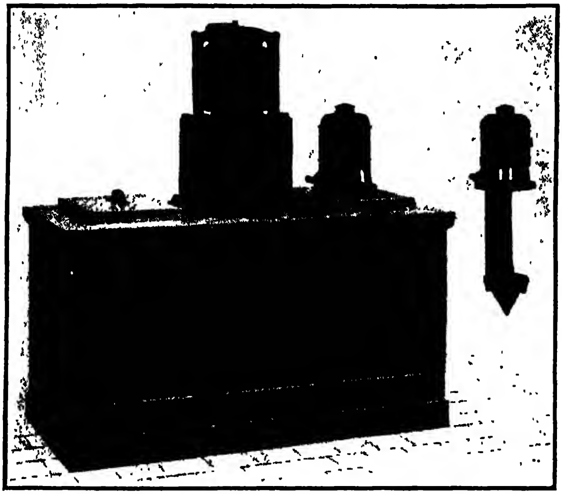
FIG. 24.—AUTOFRIGOR IN CABINET REFRIGERATOR.

A convenient, neat and efficient refrigerator for dairy products.

Fat tests cannot be made at the platform; the samples should therefore be sent to the laboratory. It is best to test each patron's milk each day, but this is hardly practicable. A composite sample may be made up for each patron by taking equal proportions from each day's milk (e.g., 1 cc. for each pound), and the test made once a week or once in ten days. With suspected milk, the test should be made when the case arises. In taking samples for the fat test, special attention should be given to taking a fair representative sample, by thoroughly mixing the whole batch of milk in the weighing can. It is best to take the sample just after the last can of milk has been poured into the weighing can. Accurate work can be done by the testers in the laboratory only when correct samples have been taken. For the composite samples, preservatives should

be added. Corrosive sublimate and bichromate of potash are commonly used, and a very small amount of these will keep samples a long time. A sample should not be kept too long, however, or a leathery cream will form on it, and when this occurs it is very difficult to reincorporate the fat into the milk serum.

Many investigators prefer corrosive sublimate to any other preservative. Jackson states that 0.5 gram of this chemical will keep 300 cc. of milk for fifteen days. All preservatives are poison-



Courtesy of Escher, Wyss and Co., Zurich, Switzerland.

FIG. 25.—AUTOFRIGOR ICE PRODUCER, WITH BRINE PUMP.

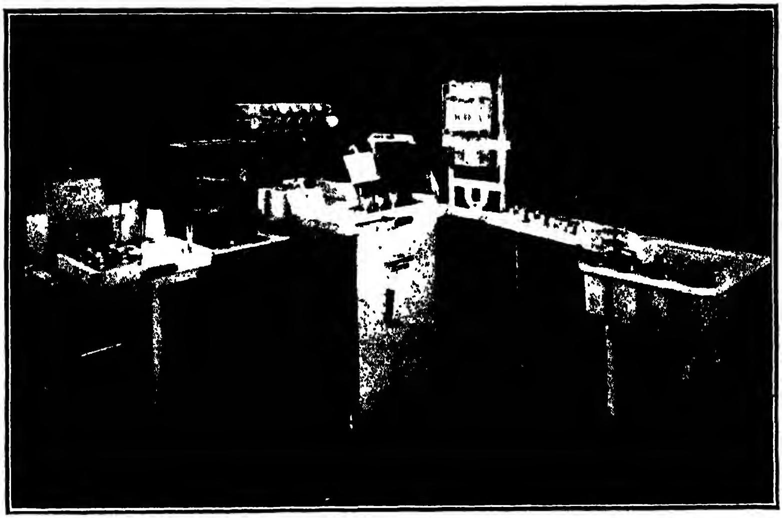
Where artificial ice is desired, this type of machine will furnish from 130 to 200 lbs. per day, and, by the use of the brine pump, a room may be cooled also.

ous, and great care must be taken in handling and storing them. Tablets of corrosive sublimate colored pink are specially prepared for this purpose and are on the market. It is important to have the preserved composite samples colored so that they may be conspicuous and therefore less dangerous.

The reduction test, like the fat test, cannot be made at the receiving platform; the sample for this test must therefore be sent to the laboratory. It would be well to have each patron's milk subjected to this test every day, but that is too much to expect. All suspected samples should be tested for reduction of

methylene blue before the question of deterioration is decided. In order to keep in touch with the general quality of each patron's milk, it is important to make the reduction test at least occasionally for every one. Such constant care tends toward general improvement in the final product.

In order to test the cleanliness of patrons in milking and handling the milk, the sediment test is also used. This may be done on the receiving platform or in the laboratory. Harding



Courtesy of Mojonnier Bros. Co.

FIG. 26.—MOJONNIER TESTER.

Model D, with electro-thermostatic control. A complete and convenient tester for milk and condensed milk.

and his co-workers report as follows on the effect of dirt on bacterial content:

Practically all of the dirt entering the milk at the farm enters during the act of milking. The use of the small-topped milk pail materially reduces the amount of dirt entering the pail, the reduction varying from 25 to 40 per cent.

The weight of dirt entering is surprisingly small. Even when the cows were very dirty and were milked into an open-topped pail, the dirt in the unstrained milk amounted to only about 10 mg. per quart. When the conditions were comparable with ordinary dairies, and the small-topped pail was used, the amount

was less than 5 mg. per quart. Under conditions comparable with the better class of market milk dairies and where the small-topped pail was used, the proportion of dirt was not over 2.5 mg. per quart.

The kinds of dirt falling into the milk vary with the condition of the cow. With hand milking, the entrance of some hair and dandruff is practically unavoidable, though the amount may be reduced by regularly brushing the cow. If the flank and udder are soiled with dried manure and other dirt, some of this may find its way into the milk.

Thorough straining removes the hair, dandruff and larger particles which form 75 to 90 per cent of the visible dirt. Undoubtedly some of the dirt goes into solution in the milk, but the amount is so slight that we did not succeed in measuring or even in detecting it.

The increase in bacterial count due to dirt entering the milk varies widely with the nature of the dirt. Hair and dandruff from clean cows have much less effect upon the bacterial count than dirt from extremely dirty cows.

The germ life on dirt from extremely dirty cows gave a bacterial count of approximately 1.5 billion per gram of dirt. Under the worst conditions, when the dirt in the milk amounted to 10.8 mg. per quart, the increase in bacterial count of the milk was about 17,000 per cubic centimeter. Under the same conditions except that the small-topped pail was used, which reduced the dirt entering the pail to 8.1 mg. per quart, the bacterial count due to dirt fell to 13,000 per cubic centimeter.

Previous studies have shown that in warm weather the use of clean utensils which have not been promptly and thoroughly dried results in immediate increase in the germ count of the milk varying from 30,000 to 1,000,000 per cubic centimeter. In the summer season the milk drawn in the morning and delivered from the farm to the milk plant has an average bacterial count of at least 50,000 per cubic centimeter. After the first six to ten hours, growth begins, and may rapidly increase the bacterial count.

In view of these facts, it is plain that variation in bacterial count as large as 17,000 per cubic centimeter due to dirt, at least in the summer season, will be promptly overshadowed by other factors. When the time interval permits growth, any attempt to judge of the conditions of cleanliness surrounding the production of a given sample of milk on the basis of its bacterial count becomes hopeless.

When the results of this study are properly understood, it will be clear that they cannot be legitimately used as an excuse for the production of dirty milk.

While it is still an open question as to what may ultimately be accepted as the most satisfactory index for the keeping quality of milk, there is no question that when the bacterial count is properly determined, it is a serviceable index for this purpose. It is not, however, an index by which the presence of dirt may be determined, for bacteria are commonly numerous in milk, and come from so many sources other than dirt that there is no constant relation between the dirt content and the number of germs present. Such being the case, the conclusive demonstration of the uselessness of the bacterial count as a means of detecting the presence of dirt is a necessary first step toward developing methods for accurately safeguarding the public against dirty milk.

The investigations of Harding and his co-workers apply especially to the city milk supply; but what is true of city milk is also true of milk for the factory. As pointed out by these investigators, milk that is bacterially clean is not always really clean. Carelessness in milking and handling makes milk very dirty. The germ count may be kept down by cooling, but the dirt incorporated in the milk is still there. While the larger particles are removed by straining, the dissolved part is still there and cannot be removed. When the milk is condensed, the dissolved portions of the dirt will be intensified in the product. As to dissolved matter, Taylor reports as follows:

The moisture in cow manure averages 83 per cent. In air-dry manure it is about 6 per cent, 5 per cent of the solid matter being soluble in milk. This would indicate that only 11 per cent of dry manure dissolves in milk, 6 per cent of this being water. Nearly 85 per cent of fresh cow manure dissolves in milk, 83 per cent of this being water. Manure in whatever condition is less soluble in milk than in water. Of the manure present in bottled milk, 91 per cent will be visible on the bottom of the bottle, leaving 9 per cent of the foreign matter in suspension.

By the dirt or sediment test, the degree of cleanliness may be estimated; but it is a mistake to suppose that the sediment test tells the whole story. It is a good guide, and when properly used helps in improving the quality of milk.

6. All the records of the various tests and weights of the milk of each patron should be kept, and the price should depend on merit. It is suggested that a premium be paid for the best milk, and a deduction made for poor milk. Such a system aids in improving the general quality of the milk, and therefore of the

manufactured products. In some plants, especially in city milk plants, a premium is offered for milk with bacterial count less than a certain number. That this is not a perfect method will be understood from the preceding discussion. It would be better if some kind of a scoring method could be developed; but the methods used in contests for scoring market milk or other products would not be suitable as they could hardly be applied in a factory where hundreds of patrons are bringing milk every day. A

Fig. 27.—Utsunomiya Dairy Barn, Sapporo, Japan.

Clean milk cannot be produced in a dirty barn. The barn need not be expensive, but attention must be given to keeping it clean. Whitewash and plenty of fresh bedding are helps.

scoring contest of the typical sort might be useful once a year but would not be a real solution of the problem of encouraging consistent excellence of product. The results of an entire year or of some other long period should be involved in awarding premiums. These results would be obtained by compiling the records from receiving platform and laboratory. A suggested method follows, indicating at least some of the factors that should be considered.

Scoring of Patrons

1. Regularity of deliveries is an important matter, for obvious reasons. On a monthly basis, full mark might be 30, for a patron who brought his milk every day, with a penalty of 1 point for each day missed.

2. At the end of the month, each patron's average fat test for the month is computed. Most factories set a standard for the fat test of milk delivered and pay for the milk accordingly. This is of itself an encouragement to produce rich milk, and the payment of a premium adds to the encouragement. A full mark of 35 may be set if the standard fat test of the factory is 3.5 per cent; or, if it is 4.0 per cent, full mark would be 40. A deduction of 1 point would then be made for each 0.1 per cent below the standard.

3. Lactometer readings should also be taken into account. It would be more logical to calculate the solids-not-fat, and score accordingly, but this would involve a great deal of extra work. Where these calculations are made anyhow, it is better to use them; but for factories that do not calculate solids-not-fat, the lactometer readings may be used. It is difficult to set a standard for these. A high lactometer reading is not necessarily a sign of good quality, and, at the same time, a low lactometer reading may be due to high fat content. The lactometer reading depends on various factors and cannot be considered independently. However, the limits may be arbitrarily set at 28 for the lowest and 33 for the highest, and full score given to 30, 1 point being deducted for each 0.1 degree above or below the two limits.

4. Alcohol coagulation of milk is very objectionable. Deduction must be made for each case that occurs. The full mark of 30 may also be given for this factor, and a deduction of 1 point for every case of coagulation recorded.

5. If records of acidity are kept, they may also be considered. For each condemned lot, either too high or too low, 1 point may be deducted from the full score of 30.

6. Where methylene blue reduction tests are made, they should be included. A full score of 30 may be awarded for perfect record, with deduction of 1 point for decolorization in 5 hours,

2 for decolorization in 4 hours, 3 for 3 hours, 4 for 2 hours, and 5 for decolorization in 1 hour or less.

7. For the sediment test, a full mark of 30 may be given, with deductions of 1 to 5 points for each case in which sediment has been observed, award to depend on the judgment of the inspector.

8. The full mark for temperature may also be 30, with 1 point deducted for each case in which the milk was delivered at a temperature above 60° F.

9. The flavor of milk is such an important factor that a full scor of 60 may be assigned to it, with a deduction of 1 to 10 points for cases of inferiority, depending on the degree of inferiority reported by the inspector.

10. The condition of the cans in which the milk is brought may be allotted a score of 20 or 25, depending on whether the fat score is 40 or 35, so as to make a total of 330, deductions being made according to the judgment of the inspector.

SUMMARY

Factor	Perfect Score	Deductions
1. Regularity of Delivery . .	30	1 point off for each failure.
2. Fat Test (monthly average).	35 or 40	1 point off for each 0.1 per cent below standard.
3. Lactometer Test	30	1 point off for each 0.1° above or below standard.
4. Alcohol Test	30	1 point off for each case of positive reaction.
5. Acidity	30	1 point off for each condemned case.
6. Reduction Test	30	5,4,3,2,or 1 point off, for each case, depending on reaction time, 1, 2, 3, 4, 5 hours respectively.
7. Sediment Test	30	1 to 5 points for each case, according to degree of dirtiness.
8. Temperature	30	1 point off for each case above standard temperature.
9. Flavor	60	1 to 10 points, depending on degree of badness.
10. Condition of Delivery Cans. .	25 or 20	According to the judgment of the inspector.
Total perfect score	330	

Factories should adopt a system adapted to their own conditions. Some such plan may be a very helpful method of promoting the production of better milk. The scoring may be used as a basis of premiums or prizes.

THE VAT ROOM

The milk received at the receiving platform is carried into milk vats either by gravity or by milk pumps. Wherever the location permits it, the gravity method is better, as it reduces the cost of installation and the labor of cleaning the apparatus. In large factories, however, the use of milk pumps is unavoidable, and sometimes it is more economical to use them than to insist on employing the gravity method. By using tanks instead of vats, factory space may be economized.

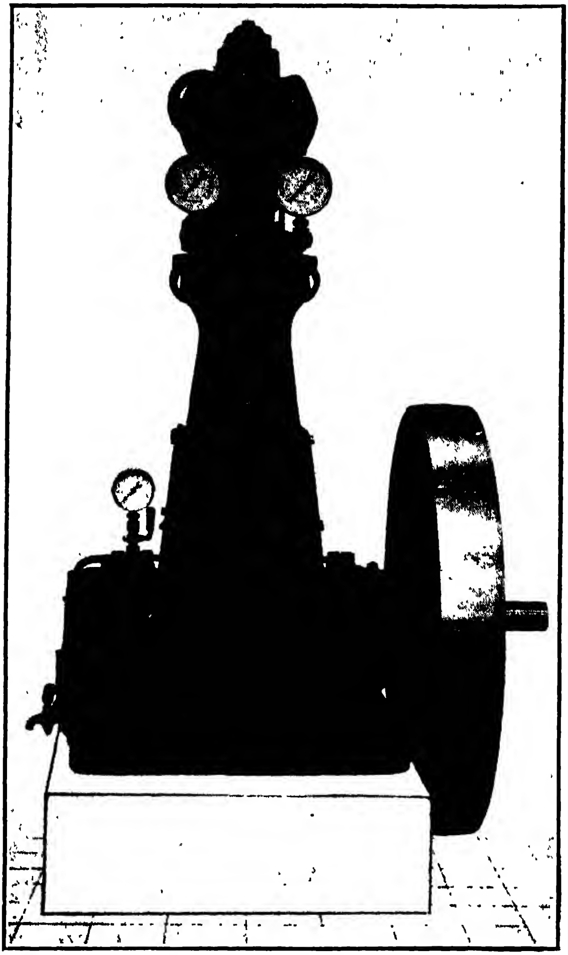
There should be vats or tanks enough to hold a whole day's receipts of milk. Ordinarily this is not necessary in a condensery, because the milk is being condensed as it is received. But in case of emergency there may be trouble or loss if there are not enough receptacles to hold the milk.

Although it may not seem necessary when milk is condensed as fast as received, milk vats or tanks should be equipped with cooling systems as well as insulated. If milk has to be stored for any length of time, especially in summer, it is very essential to keep it cooled below 50° F. Efficiency of cooling is attained by good insulation of vats and tanks. If the milk is run over brine coolers and then into insulated vats, it will remain cool for some time without additional cooling. Instead of the preliminary cooling by running over a surface cooler, milk may be cooled in the vat by the use of cooling jackets or coils. The milk should be agitated while cooling. Sometimes this is done by movable cooling coils; otherwise by agitators of some sort. Many such tanks are built with a propeller in the bottom to cause vertical circulation. In the case of small vats without mechanical stirrers, the milk should be stirred by hand while cooling.

Of the various methods of cooling liquids, the following may be mentioned:

1. Direct introduction of ice into the liquid to be cooled.
2. Addition of cold liquid to warm.

3. Flowing over metal surfaces which are in contact with a cold liquid.
4. Contact with metal surfaces kept cool by air currents.



Courtesy of Escher, Wyss and Co., Zürich, Switzerland.

FIG. 28.—VERTICAL CO_2 REFRIGERATING MACHINE.

In cooling a great quantity of milk to a low temperature, brine cooling is more efficient than a cold water system. In a condensed milk factory, a refrigerating machine of some kind is desirable.

1. The direct introduction of ice is often used as a method of cooling. Each pound of ice at the freezing point will take up, in

melting to water at the same temperature, about 144 British Thermal Units (B. T. U.). That is to say, 1 lb. of ice, in melting, will cool 144 lbs. of water through 1° F. It is assumed that the ice is at the freezing point, which is usually true, or nearly so, in summer. To state the same fact in terms of the metric system, 1 gram of ice at 0° C., in melting, takes up enough heat to cool 79 grams of water through 1° C. Tables are given both for pounds and for kilograms.

Amount of Ice, in Kilograms, to Cool 100 Kg. of Water

(Degrees C.)

From	10°	9°	8°	7°	6°	5°	4°
To 5°	5.9	4.8	3.6	2.4	1.2		
To 2°	9.8	8.6	7.4	6.1	4.9	3.7	2.4

Pounds of Ice Required to Cool 1000 Lbs. of Milk

(Degrees F.)

From	90°	85°	80°	75°	70°	65°	60°
To 60°	174	145	116	87	58	29	
To 55°	210	180	150	120	90	60	30
To 50°	247	216	185	154	123	92	62
To 45°	287	255	224	192	160	128	96
To 40°	329	296	263	230	197	165	132

In some factories this method of cooling by putting ice into the milk is practiced. It is a poor plan, both because it risks contaminating the milk, and because the water so added to the milk must all be evaporated again. It is better, if ice must be used, to use it to cool water which flows through a cooler over which the milk passes.

2. The method of cooling by mixing with a colder liquid is not to be recommended in the case of milk. To mix cold milk with warm endangers the whole, as has been already stated.

3. The third method is ideal for cooling milk. The warm milk is made to flow rapidly past a thin metal sheet, which divides the current of milk from a current of cold liquid flowing in the opposite direction. Rapid transfer of heat through the metal takes place, and the milk may leave the cooler differing only a few degrees in temperature from the cooling liquid entering. Many types of coolers have been designed on this principle.

In designing such coolers, ease of cleaning and sterilization must be carefully considered. The channels of the apparatus through which the milk flows must be straight and easily accessible for cleaning, not in the form of coils. The warm milk is made to flow downward through channels having at least one dimension small, while the cold liquid flows upward through the spaces between the milk channels. For formulæ relating to this method of cooling, see Appendix A, page 351.

A very efficient form of cooler allows the milk to flow exposed to the air over a corrugated metal vessel, through which a current

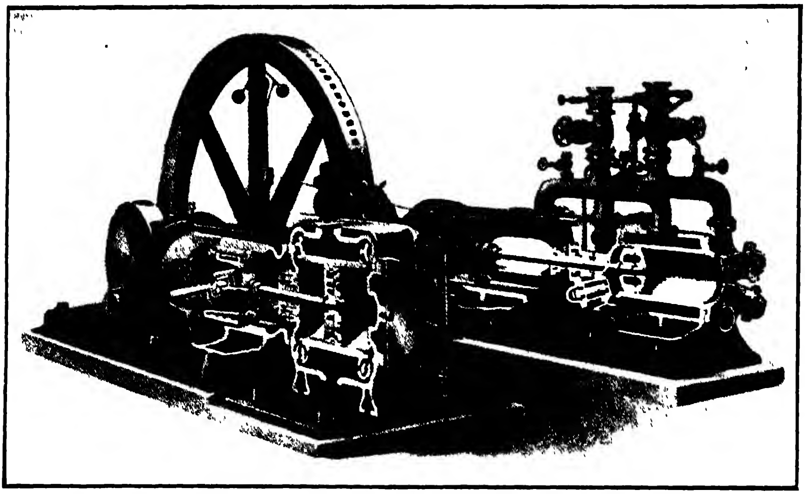


FIG. 29.—HORIZONTAL DOUBLE-ACTING REFRIGERATING MACHINE.
Full-shaded perspective sectional view. Frick Company, Waynesboro, Pa.

of cold liquid flows upward. When the temperature of the air surrounding the flow of milk is high, this method is not so satisfactory. Evaporation from the surface in any case helps with the cooling, and this is a large factor in cooling pasteurized milk which flows on to the cooler at a high temperature. This type of cooler is easily cleaned, but it has the disadvantage that dust and other contamination may reach the milk unless great care is taken. Some makes are provided with covers, but along with the manifest advantages of this plan there are several disadvantages. It increases cost and difficulty of handling, and prevents con-

tinuous observation of the milk stream, which is one of the advantages of the open type. The best way to use this type is in a dust-proof room, with the milk stream open to observation.

The same method, that is, cooling milk by means of a cold liquid, may be applied to milk contained in vats, the whole mass being gradually cooled to the required temperature by conducting the cooling liquid through a jacket surrounding the vat, or through pipes or other conductors placed within it. This method is called discontinuous, periodic, or intermittent cooling. The rate of cooling is increased by stirring. Sometimes pipes through which cold liquid is flowing are so arranged as to form a stirrer.

4. The fourth method of cooling, by means of air currents, is in general not applicable to dairy practice.

Cooling processes are very important in dairy practice. It is always wise to cool milk if it is to be kept any length of time, even if it is to be heated afterward. When the factory is running in proper order, however, milk should be condensed as fast as it is received, and as little as possible kept in the vats.

Every batch of milk to be condensed must be tested as to quality. Where the whole batch is assembled in one or more vats before being used, the taking of a fair sample is a simple matter; but when milk is condensed as fast as it is received, the taking of a representative sample of the entire batch is difficult. If the milk is led from the weighing can to the vat through a metal pipe, a very small hole in this pipe, on the under side, permits a little milk to leak out, and if a suitable vessel is placed to catch the leakage a good sample may be obtained. While such a sample is not absolutely representative, it is more satisfactory than any other which the writer has tried, and he has tried many.

In order that a uniform product may be made, it is desirable to standardize the raw milk as to fat content. For this reason the sample of milk for fat test should be sent to the laboratory as soon as possible. It is not necessary, however, to postpone the process of condensing until the test is completed, but only to reserve enough milk for the standardization, by addition of cream or skimmed milk or separation of fat. It is well to separate some of the milk early in the process, so that cream and skimmed milk may be on hand for the correction of the batch.

The whole weight of milk in the batch being known, a large part of it, say four-fifths, may be in the vacuum pan in process of evaporation. Then, when the test has been completed, it is easy to calculate the amount of butter fat which must be added or subtracted to bring the whole to standard. The requisite quantity of cream or skimmed milk is now added to the remaining fifth of the milk and it is drawn into the pan.

If any chemicals are to be added to prevent coagulation by heat, as in the manufacture of unsweetened condensed milk, they must be added in the vat room. Any addition of foreign materials other than pure sucrose is not advisable; but in some factories certain chemicals, which, while not beneficial to health, are at least not harmful, are added in order to improve the quality of the product. Calcium compounds in various forms are sometimes used. Sommer and Hart advise the use of sodium citrate or disodium phosphate to prevent the coagulation of milk by heat. These chemicals should first be dissolved in water and then added to the entire batch evenly. Otherwise an unbalanced salt content may result in a part of the milk, which may then coagulate on heating, before being drawn into the vacuum pan.

If the condensation process is to be begun after all the milk has been received, this uniform mixing is comparatively easy. If, however, the condensing process is started soon after the milk begins to be received, it is very difficult to secure uniform mixing. It is advisable in such a case to have several small vats, and, having added the requisite dose of chemicals to the contents of one vat, to pass that on to the next process, and so on. It is necessary to add solutions very slowly, with vigorous stirring, and not to make the solutions too strong. If only the very best milk is employed, there is no need of chemicals, and the author is strongly opposed to their use unless it is absolutely necessary.

After the milk vats or tanks have been emptied, they must be thoroughly washed, first with lukewarm water and then with hot water to which a washing powder has been added. After rinsing with clean hot water, steam may be blown into the vats to sterilize them. They must then be kept dry until again needed for receiving milk. Cleanliness of milk vats and tanks is of the highest importance. It is very hard to keep them dry, but very neces-

sary. If the vats remain damp, foul smells are almost certain to result. The bacterial growth of which this is an indication may cause trouble in the manufactured product. If the vats are made of tin plate, wetness may result in rusting, which is injurious both to the vats and to the milk.

Importance of Proper Fat Content in the Manufacture of Condensed Milk.—The fat content of the raw milk has a great influence on the quality of the condensed milk. The color of the condensed milk is deficient in luster if the milk has been wholly or partly skimmed. Removal of fat reduces the nutritive value of the condensed product, its keeping quality, and the yield.

Relation of Fat Content to Yield of Condensed Milk.—In order to determine the yield of condensed milk from a given amount of raw milk, the author conducted many experiments at the Hokkaido Imperial University. Unfortunately, the results were not very reliable, but varied considerably as to both quantity and quality of the product. When a very small experimental pan was used, it was very difficult to determine the so-called "striking point," becasue a sufficient amount of milk could not be drawn out of the pan for testing without affecting the final condition of the product. It was therefore necessary, in determining the striking point, to depend entirely on the appearance of the boiling milk in the pan as observed through the eye-glass. This method is very uncertain, because the progress of the boiling depends on the heat applied and on the condition of the milk itself. Besides, the appearance of the boiling milk varies with the lighting of the pan, and cannot always be taken as an index of the consistency of the product.

It may be noted here that the striking point is always determined by consistency and is not always reached at the same point of concentration. That is, when a certain consistency is reached, the batch is struck, even though the amount of evaporation may be less than average; and when the normal amount of evaporation has been effected, if the consistency is not correct, the evaporation must be carried further. This is a very important point in the practice of condensed-milk manufacture.

In carrying on the experiments above referred to, in order to avoid errors due to inability to judge of the progress of the

boiling, it was planned to catch the evaporated water by means of a surface condenser, receiving it in a graduated cylinder. This was found ineffective because some of the water escaped through the pump. A second condenser and catch cylinder were introduced, but still there was some loss, and the amount of water caught differed with different batches. In order to catch the last traces of condensed water, a sulphuric acid trap was introduced, but this was unsatisfactory because it was not possible to determine the amount of water caught by the sulphuric acid quickly enough to aid in determining the striking point. Even if all the water evaporated could be instantly determined, the method would still be defective, because, as already stated, the proper striking point depends altogether on consistency, and this is not directly proportional to concentration, for different samples of milk.

Even with the best possible control, the batches made in the laboratory differed one from another. The ratio averaged about 2.8 lbs. of milk to 1 lb. of condensed milk. According to Hunziker, 2.5 to 2.75 represents the range in practice. This difference is due partly to the fact that the laboratory product was nearly always a little thinner in consistency than the standard, and partly to the fact that it was impossible to get the whole of the batch out of the pan to be weighed.

In the effort to arrive at dependable figures for the yield of condensed milk from a given amount of raw milk, it was found that factory observations were more reliable than laboratory experiments. The factory results may seem crude in a way, but weighings of hundreds of pounds of milk to a tenth of a pound are proportionately as accurate as weighings of a few grams to the tenth of a milligram. By taking into consideration, in the factory tests, a very large number of batches, quite accurate results may be arrived at.

Out of 1400 batches of condensed milk of which data are available, 864 batches were chosen in an effort to find the relation of fat content of raw milk to yield of condensed milk. In all cases the amount of sucrose added was the same, 16 lbs. of sucrose to each 100 lbs. of raw milk. The results are summarized in the table that follows:

SUMMARY OF RESULTS ON RELATION OF FAT CONTENT OF MILK TO YIELD OF CONDENSED MILK

Per Cent Fat	Number of Batches Averaged	Per Cent Total Milk Solids	Average Pounds Milk per Batch	Average Yield Condensed Milk, Pounds	Per Cent Yield	Specific Gravity Condensed Milk, Average
0.050	1	8.750	3491.6	1110.2	31.80	1.345
1.750	1	10.185	2625.0	967.5	36.85	1 306
1.800	1	10.295	2566.6	902 4	35 15	1 333
1.926	3	10.471	2563.8	910.3	35 50	1 321
2.059	8	10 620	2853 1	1059 4	36 27	1 316
2 220	1	10.730	3241 6	1209 2	37.30	1.320
2 730	1	11.270	2275.0	910.7	35.63	1 310
2 980	1	11.615	2500.0	982 1	39 28	1 314
3 043	6	11.886	2631.9	959 2	36.44	1 310
3 145	31	11.853	5696 0	2078 3	36.49	1 309
3 214	200	12.020	5122 9	1866.0	36 42	1 306
3 330	240	11 909	8993.9	2920.5	36 49	1 305
3 426	157	11 993	7887 4	2879.4	36.51	1 305
3.524	98	12.062	7584 6	2769 8	36.52	1 304
3 629	62	12 227	6840.1	2505 3	36 62	1 304
3 727	24	12.410	7628 6	2786 4	36.53	1 305
3 842	21	12 513	4645 8	1685 2	36 27	1 304
3 940	5	12.772	5642 3	2056.3	36.44	1 305
4 040	2	12.808	7130 8	2564 2	35 96	1.307
	Total 864					
Av. 3 365	. . .	12 004	6818.2	2488.1	36.49	1.305

In this table, the first sample is skimmed milk. The lower-percentage samples are too few in number to form a basis of conclusions. The same is true of the highest group. It is quite clear from the whole series that the fat content does not have much influence on yield, if we consider those samples that are within the ordinary limits, from 3.1 per cent to 4 per cent. These batches are large enough to correspond to good factory practice, involving 5000 lbs. or more to a batch. The average concentration, expressed in Hunziker's terms, is 2.74 lbs. of milk per pound of condensed milk, a high concentration.

In order to emphasize the relation of fat content to yield in the case of all the batches having fat content from 3.043 to 4.040, a table follows in which the differences from the average in each lot are shown, indicating a gradual increase of yield with rise of fat up to about 3.5 per cent, and then a very gradual decline.

Relation of Fat Content to Yield: Deviation from the Mean

	Fat	Difference	Yield	Difference
Average of whole number	3.365	....	36.49	
	3.043	−0.322	36.44	−0.05
	3.145	−0.220	36.49	0.00
	3.214	−0.151	36.42	−0.07
	3.330	−0.035	36.49	0.00
	3.426	0.061	36.51	0.02
	3.524	0.159	36.52	0.03
	3.629	0.264	36.62	0.13
	3.727	0.362	36.53	−0.04
	3.842	0.477	36.27	−0.17
	3.940	0.575	36.44	−0.05
	4.040	0.675	35.96	−0.53

This table shows a distinct tendency for increased fat content to produce greater yield up to about 3.7 per cent fat, and a tendency for higher fat content to diminish the yield. The last group includes only two batches and may be dismissed.

If it be true, as seems likely, that fat increase beyond a certain point tends to diminish yield, this may be accounted for by the fact that, while the striking point is determined by consistency, fat in the warm sample tested has a tendency to make the sample more fluid, and so higher fat may make necessary further evaporation to reach the standard striking point. This further evaporation would diminish the yield.

The whole question has a great interest from a financial point of view. Since the milk is bought on fat analysis, it does not pay to put in more fat than is needed to give the best yield. The product should have a definite standard of fat content, and the milk should be standardized so as to yield condensed milk of that standard quality. Careful analysis of the data indicates that the effect of fat increase in the fresh milk on the yield of condensed milk is higher in the lower grades of milk than in the better grades.

Relation of Fat to the Keeping Quality of Condensed Milk.—Experience shows that a product with higher fat content is smoother and more lustrous than one with less fat. The fat-poor product is ligher in color and lacking in quality. A good condensed milk should have a fine luster and a thick, syrupy consistency. It should give a long, fine, stringy drop; and when this is held to the light it should have good transparency. The color of fat-poor samples is not only lighter but also duller than that of the richer material. When a spoonful is dropped it tends to form droplets, even though the consistency is apparently thick enough; and a drop held up to the light lacks transparency. Although in its condensed form it apparently gives the same flavor as the rich product, fat-poor condensed milk has a flat flavor when diluted.

One of the most troublesome defects of condensed milk is a tendency to become thick or pasty with keeping. This may occur within a few weeks after manufacture, or the milk may thicken gradually and become pasty after several months. This defect is due to several causes, of which deficiency in fat in the original milk is an important one. The author has proved that condensed milk made from fat-poor milk does not, in general, remain syrupy long, but tends to become pasty.

In order to test the relation of the keeping quality of condensed milk to the fat content of the raw milk, samples made from milk of various degrees of richness were kept under natural conditions and examined at intervals of six months for a period of two years. Some 700 samples were involved. The appended table gives the results of this test, showing the maximum, minimum, and average fat content of the samples in each class.

Relation of Fat Content to Keeping Quality of Condensed Milk

	Found to be Pasty at the End of				Kept Well for 2 Yrs.
	6 Mos.	1 Yr.	18 Mos.	2 Yrs.	
Number of samples....	16	39	65	125	453
Maximum fat content.	3 60	3 60	3.80	3 70	4.08
Minimum fat content..	0.05	0.05	0.02	0.05	0.05
Average fat content ...	0.982	1.153	2.501	3.010	3.382

While this table, in its averages, bears out very well the statement already made, it will be noticed that samples of low fat content and samples of high fat content are found in every class. It is clear that there must be some other factor or factors involved. The following table shows the actual numbers in the different groups.

Distribution of Samples in Various Groups of Fat Content and Keeping Quality

Fat Test	Found to be Pasty at the End of				Kept Well for 2 Yrs.
	6 Mos.	1 Yr.	18 Mos.	2 Yrs.	
Under 1 0 per cent. .	10	18	11	2	2
1 0 to 1.5 per cent .	1	4	7	13	1
1 5 to 2 0 per cent. .	1	7	5	3	4
2 0 to 2.5 per cent. . .	1	5	4	7	5
2 5 to 3 0 per cent. . .	0	0	1	3	3
3 0 to 3 5 per cent. .	2	4	17	64	410
Over 3 5 per cent. .	1	1	20	32	23

The same data are arranged in the form of percentages in the next table:

Percentage of Each Keeping Class Found in Each Fat-content Class

Fat Test	Found to be Pasty at the End of				Kept Well for 2 Yrs.
	6 Mos.	1 Yr.	18 Mos.	2 Yrs.	
Under 1 0 per cent. . . .	62 50	46 15	16 92	1 61	0 44
1.0 to 1.5 per cent. . .	6 25	10 26	10.77	10 48	0.22
1.5 to 2 0 per cent . .	6.25	17 95	7 69	2 42	0 86
2 0 to 2 5 per cent. . . .	6 25	12 82	6 15	5 64	1.11
2 5 to 3 0 per cent. . .	0 00	0 00	1.54	2.42	0 66
3.0 to 3 5 per cent. . . .	12.50	10 26	26 15	51.61	90.51
Over 3 5 per cent. . .	6.25	2.56	30 78	25.82	6.18
Total	100.00	100 00	100 00	100 00	100.00

PERCENTAGE OF EACH FAT GROUP FOUND IN EACH KEEPING CLASS

Fat Test	Found to be Pasty at the End of				Kept Well 2 Yrs.	Total
	6 Mos.	1 Yr.	18 Mos.	2 Yrs.		
Under 1.0 per cent.......	23.26	41.86	25.58	4.65	4.65	100.00
1.0 to 1.5 per cent	3.85	15.39	26.92	50.00	3.85	100.00
1.5 to 2.0 per cent.......	5.00	35.00	25.00	15.00	20.00	100.00
2.0 to 2.5 per cent.......	4.55	22.73	18.18	31.82	22.72	100.00
2.5 to 3.0 per cent........	0.00	0.00	14.28	42.86	42.86	100.00
3.0 to 3.5 per cent.......	0.40	0.81	3.42	12.88	82.49	100.00
Over 3.5 per cent.......	1.22	1.22	24.39	39.02	34.15	100.00

It is clear from these data that in order to make a long-keeping condensed milk it is necessary to use a milk having not less than 3 per cent of fat. This may be because the fat tends to give a smooth, fluid consistency, while casein has a tendency to "set," thus causing a sort of coagulation of the condensed milk. Fat seems to hinder this setting.

THE RELATION OF FAT CONTENT TO THE MANIPULATION OF THE VACUUM PAN

Milk that is poor in fat foams more in the vacuum pan than richer milk, thus making the manipulation of the pan difficult. With skimmed milk the foaming is excessive, and much care is required to keep the milk from going over into the condenser. In laboratory practice a piece of paraffin, wax, or fat or a drop of oil is often added to a boiling liquid to decrease foaming, the added material forming a film on the surface of the boiling liquid. In boiling milk the fat is not separated into a surface film, but it seems to have a real influence in diminishing foaming. This must not be taken to mean that rich milk does not foam in the vacuum pan, but only that it foams less than poor milk. The manipulation of the pan is simpler when foaming is minimized. High fat content checks it to some extent, but is not a sufficient safeguard, other factors being involved. The degree of vacuum and the steam pressure applied to the coils and jacket, for in-

stance, have great influence, and all these belong to the art of manipulating the vacuum pan.

When the milk foams badly, it is difficult to avoid loss of milk by boiling over into the condenser, unless the rate of suction into the pan is checked. The checking of the suction in turn delays the completion of the process. Experiments under factory conditions show that on an average it took one hour and twenty-six minutes to suck 3140 lbs. of skimmed milk into a vacuum pan 4.5 ft. in diameter, while it took only one hour and twenty minutes to suck 3134 lbs. of whole milk into the same pan. This is at the rate of 27.4 minutes per thousand pounds for skimmed milk and 25.5 for whole milk.

The experiments also show that skimmed milk takes longer to condense to a proper consistency than whole milk, 38 minutes per 1000 lbs. for skimmed milk and 36 minutes for whole milk, under the same conditions. The delay in condensing the skimmed milk is partly due to delay in the suction, and if the time of suction could be equalized there would not be much difference in the time of condensation. The delay in condensation of skimmed milk is not due to difficulty of evaporation but to the evaporation of more water. In the above cases, 1743 lbs. of water were evaporated from a batch of skimmed milk and 1467 lbs. from a whole-milk batch. The time required for evaporation of 1000 lbs. of water from skimmed milk was 66.1 minutes, and from a batch of whole milk, 74.8 minutes.

THE HEATING ROOM

The milk is led from the vat to the heating room either by gravity or by means of a pump. This room is so called because in it the milk is heated before being sucked into the vacuum pan. Formerly the heating was done in a large round vessel called the "hot well," from which the milk was allowed to flow into the sugaring vessel, which was called the "sugar well." The two wells were usually in the same room, which was called the "well room."

The heating of the milk in this room is really the first process in the manufacture of condensed milk. The purpose of heating is three-fold: to kill bacteria, yeasts, and molds which may be

present in the milk; to facilitate the solution of the sugar; and to prevent burning the milk by contact with the surfaces of jacket and coils. As to the first of these purposes, it is possible to heat

Courtesy of Mojonnier Bros. Co.

FIG. 30.—SMALL CONDENSERY.

In a small condensery, the gravity method may be used to advantage in conveying milk, etc. Gridley Dairy Company's condensing arrangement.

the milk hot enough to sterilize it. This, however, is not advisable. Reinfection is very likely to take place at later stages of

manufacture, even if the milk is sterilized before evaporation. Fermentation in the condensed milk and the growth of "buttons," as well as thickening of the product, may be caused by one or another of several molds and other microörganisms; but deterioration of the canned product by the growth of microörganisms is not a frequent occurrence. One reason for this is that the presence of a heavy percentage of sucrose in sweetened condensed milk strongly hinders the growth of most bacteria. The important thing, in heating the milk at this opening stage, is to kill any pathogenic bacteria that may be present. For this purpose, a temperature of 145° to 180° F. (63° to 82° C.) is sufficient. Some spore-forming bacteria may escape destruction, but it is unusual for trouble to come from this cause. One defect that sometimes occurs is the bitter taste produced in unsweetened condensed milk by the growth of *Bacillus panis migula*, or some organism closely resembling it, having a thermal death point of 250° F. Studies by Nishizaki and Wakita indicate that condensed milk is, in general, a poor medium for the growth of bacteria.

Sucrose is a readily soluble sugar, but it does not dissolve rapidly in cold milk. In hot milk it dissolves very readily. Hunziker assumes that if undissolved sugar passes into the vacuum pan, the crystals become nuclei for the milk sugar to crytallize on, forming gritty condensed milk. In reality, the causes of gritty milk are to be sought elsewhere. The author has shown that any undissolved sugar in the sugar well is dissolved in the vacuum pan. The cause of gritty milk is to be found primarily in the method of cooling and agitation during cooling. It is, however, always best to dissolve all the added sucrose before drawing the milk into the vacuum pan.

While not much attention has been paid to this point, the heating of the milk before it is drawn into the pan is very essential to prevent it from burning on to the heating surfaces of the pan. If cold milk is drawn in, it will settle to the bottom until its temperature rises to the boiling point. During this time, the milk immediately in contact with the heated metal surface becomes superheated and burns fast to the surface. This is detrimental in several ways. First, it is likely to give a burned taste to the condensed milk. Second, it may cause lumpiness in

the product. Third, it lowers the heat conductivity of the pan and thereby retards evaporation and causes waste of steam. If the milk is hot when drawn in, the initial heat is sufficient to cause it to boil immediately. The applied heat added makes the milk boil violently, and the self-agitation prevents any settling, with the result that there is no burning on to the heating surfaces.

The heating that is done for these purposes is known as "preheating" or "forewarming." The vessels in which it is done are called "preheaters," "forewarmers," or "hot wells." Many kinds of heaters are in use. Formerly the general method was to place the milk in open vessels of about 5000 lbs. capacity and blow in live steam until the desired temperature was reached. Objection has been made to this method because of the possibility of introducing harmful substances along with the steam, and because the water from the condensation of the steam has to be again evaporated in the process of condensing the milk. In spite of these objections, this method, with proper precautions to insure clean steam, is a good one, and is the most efficient possible, because all the heat of the steam is transferred to the milk very rapidly, and thus the heating can be done in a very short time. See Appendix B, page 353.

In order to avoid the disadvantages of heating with direct steam, jacketed pans have been used for preheating. When this is done it is necessary to provide stirrers, to prevent burning the milk fast to the pan, and to have the largest possible heating surface, in order to secure rapid heating. Economy demands that all the latent heat of the steam be utilized; and a little carelessness, such as allowing live steam to escape from the drip, may cause considerable loss. In order not to delay the condensing process, when a heater of this kind is used, it is well to have two, so that one vat may be heated while the other is being sucked in.

Some authorities advocate coil heaters, which are perhaps more efficient than the jacket system. There are a number of coil heaters now on the market. The coils must move about in the milk. Stationary coils would be worse than a jacketed pan without stirrers. With enough heating surface, this type of heater takes a reasonably short time. Here, again, it is well to have more than one heater; or the heater may be in sections, the milk passing automatically from one to the next and so into

the vacuum pan from the last section. Instead of coils, revolving hollow disks are used in some cases, the steam flowing through the hollow in the disk. One disadvantage of the coil or disk heaters is that they require more floor space than other types, and another is that the coils or disks are more troublesome to clean than simpler apparatus.

Continuous pasteurizers of various types are often used. They are very good and efficient heaters, comparatively simple in operation and easy to clean. The Jensen type minimizes the use of milk pumps. With all their good points, however, they have certain disadvantages. Ordinarily, they have not sufficient capacity, and the cost is comparatively high for the capacity. It is difficult to heat milk above 180° F. without sacrificing the efficiency of the machines. On account of these disadvantages, the use of pastuerizers alone for heating milk in condensed milk manufacture is not to be recommended. It is, however, a good plan to use these machines as a supplement to jacket or coil heaters. They may also be used in connection with direct steam heating. The milk may be heated to about 140° F. (60° C.) in the continuous pasteurizer, and the rest of the heating done by direct steam, jacketed pan, or coils.

The temperature to which the milk should be heated depends on circumstances. As far as the dissolving of sugar and the killing of disease germs is concerned, the pasteurizing temperature is sufficient. There is no particular benefit, from the point of view of avoiding burning, in a very high temperature for preheating. There are, however, some other factors which must be considered. A disadvantage of setting too low a temperature for the standard is that, if by accident the temperature falls a little, it may be low enough to cause lumpy condensed milk. Hunziker states that most condensed milk factories use temperatures from 180° to 200° F. (82° to 93° C.). Rogers and his co-workers state that when milk is preheated above 205° F. the tendency of the product to thicken with time is much increased. From the bacteriological point of view, satisfactory results may be obtained by preheating to 63° C. (145° F.). The product in this case does not thicken, but its low viscosity permits the separation of cream. Everything considered, it would seem that 200° F. (93° C.) is a good standard to set for the preheating temperature.

THE SUGARING ROOM

In the case of unsweetened condensed milk, the heated milk is drawn directly into the vacuum pan from the heating apparatus. For the sweetened product, the addition of the sugar is the next step. This may be done in a sugar well immediately adjoining the hot well; but it is convenient to have the place for adding the sucrose at a little lower level if the gravity method of transferring the milk is used, or, if a pump is employed, the sugar well may be near the vacuum pan.

The importance of sucrose in the manufacture of sweetened condensed milk may be seen from the fact that the keeping quality of the product is almost entirely due to the presence of this sugar. Sucrose, when in concentrated solution, has the power of inhibiting bacterial growth, the power being greater with greater concentration. The amount of sugar used as a preservative for condensed milk must not be too great, or the food value of the product will be too much reduced. Sweetened condensed milk is really a sort of preserve, made with milk solids and cane sugar.

Hunziker states that from 12 to 18 per cent of sucrose is added to the fresh milk in the manufacture of sweetened condensed milk, and that 16 per cent is the usual proportion. The author's experience indicates that 16 per cent is the most satisfactory. In general practice, the amount of sucrose is calculated on the weight of milk, with no reference to the total milk solids in the milk. In order to secure a uniform product, the sugar added ought to be calculated on the basis of total solids in the milk; but while this is theoretically best, it would be difficult to carry out in practice.

The table, page 154, gives results of experiments on the relation of percentage of sucrose added in making sweetened condensed milk to the keeping quality of the product, as well as to the yield. More than 500 batches were included in the tests.

It has already been noted that, while the fat content of the raw milk has little effect on the yield of condensed milk, it has a notable effect on its keeping quality, as to consistency. In the series here tabulated, the amount of sucrose used is small in the cases where the fat percentage is small; and the two samples of skimmed milk evidently have their keeping quality determined

Relation of the Percentage of Added Sucrose to the Yield and Keeping Quality of Condensed Milk

Average Per Cent Sucrose Used	No. of Batches	Per Cent Fat in Fresh Milk	Per Cent Sucrose in Product	Yield Per Cent Fresh Milk	Incubator Keeping Test, Weeks	Quality by Aging Tests, Years
12.46	3	0.05	38 49	28 83	1 33	0.50
13.48	23	0.13	44.22	30 32	1 95	0.61
14 41	18	1.61	45.09	32.46	6.33	1 30
15.19	28	1.54	44 70	33 91	7 32	1.34
15 62	86	3.14	43.80	35 55	8.05	1.66
16 00	282	3 48	43 64	36 44	9.24	1.78
16.33	53	3.23	42 10	38 60	8 75	1.79
17 88	12	3 24	45 01	39 28	9.75	2.00
18.28	2	3.56	45 93	39 85	10.00	2.00
Av. 15.77	.. ....	3.05	43 63	36.05	8.41	1.66

far more by the low fat than the low sugar. Setting aside all the groups below 3 per cent fat, the following table is obtained:

Relation of Added Sucrose to the Yield and Keeping Quality of Condensed Milk, with Batches of Fresh Milk Having 3 Per Cent or More of Fat

Average Per Cent Sucrose Used	No. of Batches	Per Cent Fat in Fresh Milk	Per Cent Sucrose in Product	Yield Per Cent Fresh Milk	Incubator Keeping Tests, Weeks	Quality by Aging Tests, Years
14.62	6	3 46	42.32	34 99	7.83	1.83
15.00	4	3 49	42.44	35 33	9.25	2.00
15.62	76	3.36	42 83	36 39	8 36	1.76
16.00	282	3 48	43 64	36 44	9 24	1.78
16 32	48	3.36	42 14	38 55	9 13	1.86
17.20	11	3 27	44.01	39 44	9 27	2.00
18.24	2	3.56	45 93	39 85	10.00	2.00
Av. 15.89	....	3.44	43.33	36.72	9.05	1.78

It is clear from this table that the poor keeping quality of the lower groups in the former table is due not to lack of sucrose but to lack of fat. In the latter table the fat differences are practically eliminated, and the columns of keeping quality show that there is no difference worth considering due to variations of sucrose from 14.6 to 18 per cent. In the column of yields, it is clear that there is a fairly consistent increase, as would be expected. The standard deviation of the percentage yield is 1.97, while that of the percentage of sucrose added is only 1.17. Dividing the former by the latter, we get 1.68, which may be considered as a factor for the increasing yield of sweetened condensed milk per unit amount of sucrose added between the limits of 14 and 18 per cent. Therefore, for 1 lb. of sucrose added to the fresh milk, an increased yield of about 1.68 lbs. may be expected.

Since no putrefied samples were found among this entire lot, we may conclude that 15 lbs. of sucrose per 100 lbs. of fresh milk is sufficient for all practical purposes so far as keeping is concerned. While from the economic standpoint the more sucrose is added the lower is the cost of production, it is obvious from the standpoint of nutritive value that excessive quantities of sucrose are inadvisable. For the preservation of the milk, which is the sole purpose of using sucrose, 15 per cent is enough. As much as 16.5 per cent may be permissible.

Since the object of adding sugar to the milk is to preserve it, the sugar used must be the one having the greatest preserving power. Easily fermentable sugars are detrimental. Glucose, for instance, is comparatively cheap and has good sweetening power, but because it is easily fermentable it is entirely unsuitable for use in making condensed milk. If sweetening were the purpose of putting in the sugar, powerful sweetening agents, such as saccharin and dulcin, might be used. Dulcin is now used to some extent in Germany to sweeten preserves. Neither of these has any preserving power, and they should never be used in making condensed milk.

Sucrose, $C_{12}H_{22}O_{11}$, when pure, is difficult to ferment, especially in strong solution. It is therefore the most suitable of all available sugars for use in making condensed milk. In America, as well as in Japan and elsewhere, cane sugar is mostly used. In Europe, where much beet sugar is produced, this is often used

instead of cane sugar. Both cane sugar and beet sugar consist of the disaccharid, sucrose, and have the same chemical properties when pure. In America, it is said that condensed milk manufacturers have a prejudice against the use of beet sugar. This may be due to some factories having tried poor shipments of beet sugar. At the present state of perfection in the manufacture of beet sugar, there is surely no reason why it may not be used in this case as well as cane sugar. As to the possible presence of glucose as an impurity, this is more likely to occur with cane than with beet sugar. It is also said that the price of beet sugar is higher than that of cane sugar. This can hardly be true to any considerable extent in the long run. At any rate, the purity of the sugar used, and not the price should be the governing factor in choosing. Cheap sugar is almost sure to prove a poor economy.

At the California Experiment Station, beet sugar was compared with cane sugar for canning fruits and similar uses. Both kinds gave exactly the same results. Some of the fruit canners had been prejudiced against beet sugar, but the results gave no support to their objections. There is no more reason why beet sugar should not be used in the manufacture of condensed milk. It is sometimes claimed that beet sugar is less sweet than cane sugar. This is true, but it is no argument against using beet sugar for condensed milk. The purer a sample of sucrose is, the less sweet it is and the less sugary is its odor. Very pure cane sugar has little odor and is less sweet than that which has glucose as an impurity. Therefore, the argument that beet sugar is less sweet than cane may be used as a proof of its fitness for making condensed milk.

Too much attention cannot be given to the selection of a good grade of sugar. If a poor sugar is used, not only is there danger of fermentation, but the product will sooner or later change in color, flavor, and consistency. Although it may look all right when first made, the color will eventually change to dark brown. This will occur sooner or later, according to the amount of impurity and the temperature at which the product is kept. If glucose is present in the sugar, the condensed milk will develop a so-called "sugary" odor, which is very disagreeable. If yeast is present along with glucose, "blown" condensed milk will result.

The importance of keeping the sugar in a clean, dry place is

not less than that of selecting a high grade. Wet sugar may undergo various changes under different circumstances. Invert sugar may be produced, with very bad results, as already shown. Fermentation, resulting in development of acid, is one of the possibilities. Molds may also develop. Wet sugar forms crusts, and these break up into lumps which cause trouble in the sugar well, and possibly in the final product. The room in which the sugar is kept must be protected from communication with the outside, except such as is absolutely necessary. Free communication, even through a small hole, may invite honey or other bees. Not only does this mean loss of sugar, but bees carry bacteria and impurities, which may affect the quality of the condensed milk. Ants must also be kept out.

There are many methods of adding sugar to the milk. Generally, the heated milk is conveyed to the sugar wells, in which the sugar is dissolved, and from which it is drawn into the vacuum pan. In some factories the heating is not limited to the heaters proper, but the sugaring vessels are also heated. This is sometimes necessary, for the temperature of the milk is considerably reduced by dissolving the sugar. Even if the pasteurization of the milk is successfully accomplished by the first heating, and the milk is hot enough to dissolve the sugar perfectly, any microörganisms that may be present in the sugar will not be killed by the reduced temperature at which the solution of the sugar takes place. There is another and more important reason for reheating in the sugaring vessel: this should be done in order that the milk may enter the vacuum pan so hot as to boil violently and so not be in danger of burning fast to the pan.

Sugaring is sometimes done uniformly throughout the operation; that is, the whole of the sugar is dissolved in the whole batch of milk. More generally, it is dissolved in a portion of the batch, a portion being drawn into the pan without adding any sugar. To insure uniformity, the first method might seem better than the second, but the author's experience indicates that the second method is preferable. If sugar is not present at the first stage of condensing, evaporation is more rapid; but as the operation proceeds, there is a tendency for casein to burn fast to the pan, making the operation of the pan difficult. The introduction of sugared milk decreases this difficulty. Good judgment in

drawing in milk with and without sugar at the proper time not only shortens the time of condensing, but gives a better-keeping product. The keeping quality of the condensed milk depends somewhat on the time of contact with the vacuum pan. This point will be taken up later. It is one of the essentials in the successful manufacture of condensed milk to finish the condensing process in the shortest possible time. Drawing in unsugared milk in the first stage and good judgment in the operation of the pan are important factors in shortening the time of the process.

This method is sometimes carried too far, most of the milk being drawn in unsugared and the sugar dissolved in a very small part of the batch. If too concentrated a solution of sugar in milk is made, the colloidal condition of the casein is disturbed, and part of it separates out in the form of a flocculent coagulum. This is, of course, detrimental, and the sugar should not be dissolved in so small a part of the milk.

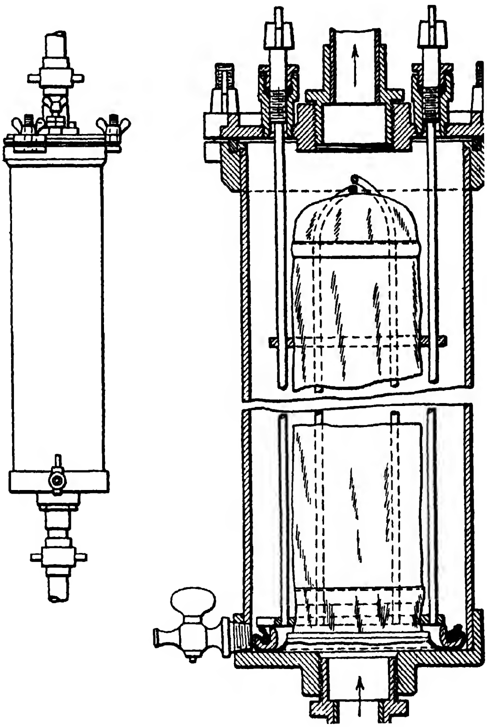
Dissolving the sugar in water is sometimes recommended and has been practiced. This assures perfect solution of the sugar. The obvious disadvantage is that the water must be again evaporated, thus wasting steam and consuming time. If a sugar solution is sucked in after all the milk is in, the operation of the pan is rendered difficult and the operation delayed. If this method is used, the water solution of sugar should be drawn in gradually after a little more than half of the milk is in. The solution should be drawn in along with the rest of the milk. The reason given for recommending this method is that it prevents the entrance of undissolved sugar into the vacuum pan. The author's experience indicates that there is no occasion to fear bad results from the entrance of undissolved sugar crystals into the vacuum pan.

It is said that condensed milk has been made in which the sugar was added after the evaporation was finished. This is not a practicable way of making a product comparable to ordinary sweetened condensed milk. It is very difficult to dissolve sugar in thick milk.

According to the author's experience, the best method seems to be to let the first half of the milk be sucked into the pan with no sugar, and then to dissolve the proper amount of sugar in the remaining half of the milk. The sugar then dissolves easily

without any disturbance of the state of solution of the milk constituents, and the rate of evaporation is increased.

The sugar storage room is usually directly over the sugaring room. The weighed quantity of sugar is led through a chute to the dissolving vessel, by gravity. Where sugar storage is on the same level as the dissolving vessel, conveyors are used. The

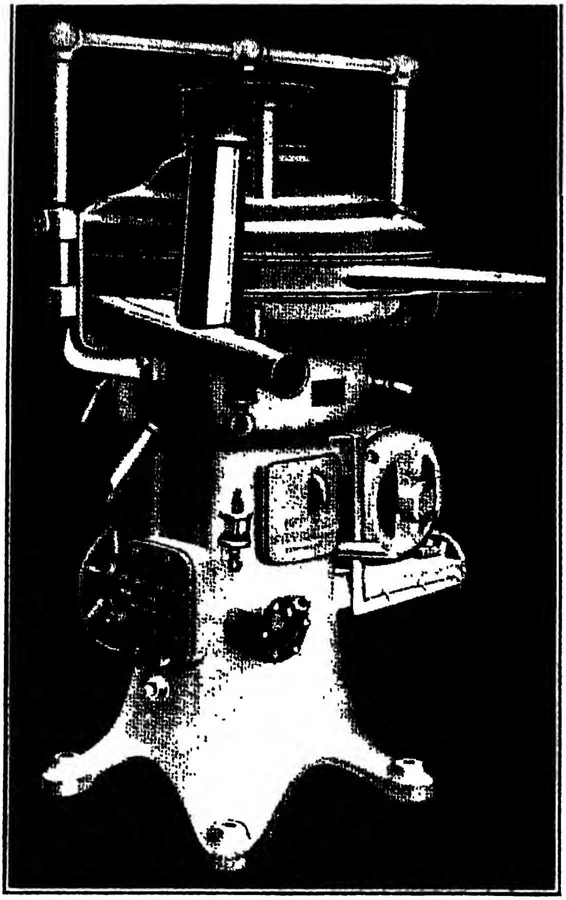


Courtesy of Arthur T. Barlass Co., Chicago.

FIG. 31.—MILK FILTER, ELEVATION AND SECTION.

supply of sugar must keep pace with the supply of hot milk. If too much sugar is supplied, the temperature of the milk falls and the rate of solution is slowed down. When a dissolving tray with a sieve bottom is employed, if too much sugar is put into it at once, the bottom is liable to be clogged with crystals of sugar in thick syrup, and the milk may overflow. To insure ready and perfect solution, the milk should be stirred. A rotary stirrer is conveni-

ent when the sugar is thrown directly into the sugar well. Where a sieve-bottom tray is used, hand stirrers, such as wooden paddles, may be used.



Machine designed by Fort Wayne Dairy Equipment Co., Fort Wayne, Indiana.

Fig. 32.—Claro-Heater.

Instead of being filtered, the milk may be passed through centrifugal clarifiers. The claro-heater, it is claimed, will clarify and heat the milk for condensed milk.

The sugar should be clean, without foreign particles. As commercial sugar often contains these, it is very necessary to strain the sugared milk through fine-mesh strainers before it is

sucked into the vacuum pan. The milk itself is also likely to contain some dirt, which must be removed as completely as possible. When milk is heated, small particles of coagulum are likely to be formed, especially if any abnormal milk was mixed in the batch. This material must be removed if first-class condensed milk is to be made. Sugared milk is more difficult to strain than pure milk. A gelatinous coagulum often forms in the milk after the addition of sugar, and this soon clogs up the meshes of the strainer.

It is best to strain the milk on receipt at the platform, or by means of a strainer placed in the path of the milk from the weighing can to the vat. This takes out all the coarser dirt. The fine dirt that escapes this first straining is, partly at least, entangled in the coagulum which forms on heating and sugaring. The last straining is that of the sugared milk; this may be done in two steps, with a coarser and a finer strainer. These must be so arranged that they can be readily exchanged and cleaned without much interruption, as they are sure to be frequently clogged with dirt.

THE PAN ROOM

The sugared milk is next led into the pan room, where it is condensed. The method that is almost universally used is evaporation under reduced pressure in a vacuum pan. In some factories the pan is placed in the well room. In others it is in a special room. In large factories it is usually located on the top floor. The sugared milk is usually sucked into the pan directly from the well. If the distance is too great, it is sometimes conveyed by a milk pump to a supply tank. This is not advisable, as it is best to have the sugaring well and vacuum pan close together.

Various forms of vacuum pans are in use, but in principle they are the same. They differ in size, shape, and heating surfaces. The sizes vary from 3 ft. in diameter up to 7 ft., the 6-ft. pan being the commonest.

The two requirements for milk evaporation are rapidity and low temperature. The vacuum process lends itself admirably to both of these requirements. The low temperature makes pos-

sible the use of exhaust steam for heating. In the early stages of evaporation, milk will boil at a temperature only 5 degrees Centigrade (9 degrees Fahrenheit) below that of the heating surface, and at a later stage twice this difference is sufficient. The boiling point of sugared milk at any pressure is about one-half degree Centigrade above that of water at the same pressure. A table of temperatures, etc., will be found in Appendix C, page 356.

Vacuum.—In ordinary engineering practice, vacuum is expressed in inches of mercury, and denotes the difference, as measured by the height of a mercury column, between the pressure in the pan and that outside, due to the atmosphere. The standard atmospheric pressure is that at sea level at a temperature of 62° F., and may be taken as 14.7 lbs. per square inch. Under the same conditions, 30 ins. of mercury corresponds to an absolute vacuum. If the pressure in the vacuum pan be denoted by AP (pounds per square inch), the following formula holds: $AP = \frac{14.7 \times (30 - V)}{30}$, where V is the indication of the vacuum gauge in inches of mercury.

Atmospheric pressure decreases as altitude increases. For a given pressure in the pan, the reading of the gauge will be different at different altitudes. If a gauge reading of 26 is satisfactory at sea level for the making of condensed milk, at an altitude of 7000 ft. the proper figure will be about 19 ins. A table for these relations will be found in Appendix D, page 357.

Vacuum Pan.—The simplest type of vacuum evaporator is that called "single effect." The word "effect" is taken from the French "*effet*," which, in describing such apparatus, means vacuum pan. Where several such pans are used in series, the vapor from one serving to heat the next, the arrangement is called a "multiple-effect" system. Such evaporators are used in the manufacture of sugar and of tanning extracts. The liquid in any one of the effects represents one stage in the process, that in the first effect being the least condensed and being heated to the highest temperature. Successive effects contain thicker and thicker liquids and are heated to lower and lower temperatures. The economy of fuel thus effected is very great. It has not,

however, been considered practicable to use multiple-effect apparatus for condensing milk.[2]

The various types of single-effect evaporators used in making condensed milk differ in general only in minor particulars. They all have a cylindrical body with jacket and coils for heating and are used only for condensing. Another distinct type has revolving coils for heating and cooling as well as for agitation. This latter type is an invention of the author and has only recently been put on the market.

The customary type of evaporator has a jacketed copper cylinder below, and a dome on top, from which the vapor is carried to the condenser through a large goose-neck pipe. As has already been noted, the most-used size is 6 ft. in diameter. The height is also usually 6 ft. Sometimes the height is greater and the diameter less, for the same capacity. The makers of the taller form claim that it is less likely to permit splashes to go over into the condenser. Under certain conditions this is true; but the increased velocity of the stream of vapor in the narrower cylinder tends to draw the splashes higher. The greater depth of the liquid in the narrower vessel retards evaporation because of the greater distance that bubbles of vapor must traverse in order to escape from the free surface. This is especially disadvantageous in the last stage of evaporation, when the liquid has become thick, and is liable to cause superheating, which is injurious to the quality of the product. When the milk foams much, the danger of milk climbing over into the condenser is greater in the narrower pan.

Usually, only the bottom of the pan is jacketed, the jacket being riveted or welded fast to the cylinder. In some makes, the lower part of the vertical wall of the cylinder is also provided with a jacket. This is not advisable, first, because jacket heating is not so efficient as heating with coils, since in the latter case the condensing steam gives all its heat to the milk with no loss by radiation into the air. A second reason for not jacketing the wall is that when this is done the milk is likely to burn fast at the surface of the liquid. The bottom jacket is a necessity, for

[2] Success in the use of a double-effect evaporator is claimed by one maker of apparatus (1927).

the coils cannot be used until they are covered with milk. If they are used when the milk is beginning to enter, it will burn fast to them. If a side jacket is used at all, it should be separately connected and only used when the pan is full of milk. When the milk is first drawn in, it boils because of its own heat and the reduced pressure upon it. But unless the steam is turned into the bottom jacket, the boiling will cease quickly and the milk settle. Very soon after the milk begins to enter, the jacket is covered, so that the heat can be applied to it. The jacket does not need to be very deep. The outside is frequently of cast iron.

The dome is usually riveted to the cylinder. To insure air-tightness it would be better to braze or weld it on; but riveting is better because it may become necessary to take the dome off for repairs. It is difficult to make the joint air-tight by riveting; moreover, the joint is not smooth, leaving crevices in which milk may lodge. These disadvantages may be offset by heavily tinning the inside to fill the crevices. The dome is usually of sheet copper, conical or hemispherical in shape. It is well to have as much free space as possible, for the reasons already given. There should be a manhole in the dome, though in smaller pans it is sometimes placed elsewhere. With a properly arranged rubber gasket there need be no difficulty in making the manhole cover fit air-tight. The slanting position of the cover when the manhole is in the dome makes it easy to adjust, as the pull of the vacuum holds it in place.

In the center of the cover of the dome manhole, there is a piece of heat-resisting plate glass, resting on a rubber gasket or some suitable elastic cement. On the opposite side, one or two other windows are provided. These are called "eye-glasses." If the pan is in a well-lighted room, the fixed window or windows in the dome may be turned toward the window of the room, and natural light used to illuminate the inside of the vacuum pan. Otherwise, electric light bulbs are so placed that they throw light into the interior through the eye-glasses. It is better to have only one window opposite the manhole if enough light can be secured in this way, as additional windows only mean more danger of breakage and leakage. The blow-cock is situated on the dome within easy reach of the operator. In the course of evaporation the use of the blow-cock should be avoided if pos-

sible; but when necessity for it arises, it must be immediately available. This cock must work very easily and yet be air-tight. In the most successful runs, it is only opened to break the vacuum at the close of the operation.

There is also a thermometer on the dome. This is usually arranged to take the temperature in the vapor space of the pan, but sometimes has a long stem reaching into the boiling milk. The latter form is better, but it is more expensive and more liable to breakage. Ordinarily, the temperature of the vapor and the boiling milk are closely related. The author has made thousands of observations with thermometers in both the vapor and the milk. In the early stages the temperatures are nearly the same, but as the milk gets thicker the difference increases. At the end of the process the milk is sometimes as much as 15° or 20° F. hotter than the vapor. The average difference throughout the operation is 4.3° F. An experienced operator can make condensed milk successfully without a thermometer dipping into the milk; but it is better to have it, since temperature control is one of the most essential factors of success. Successful control of temperature requires much skill on the part of the operator. See Appendix E, page 358.

The vacuum gauge is usually connected to this part of the pan, but sometimes to the goose-neck. It is often grouped with other gauges and placed on a board so located as to be easily seen by the pan operator. This gauge must be examined every morning before the pan is put into operation, to be sure that it is in working order. Sometimes the tube leading to it becomes clogged and so hinders the proper working of the gauge.

The heating coils in the vacuum pan are made of copper tubing and are usually in three sections. They are placed in the lower part of the pan. The top and middle sections have their steam inlets and outlets on the side of the cylinder; but the lower section has its outlet into the jacket, and its inlet on the side of the cylinder. The lower coils are made of smaller pipe than the upper. In a 6-ft. pan the lower section is usually made of 3-in. diameter tubing, while the other two are 4 ins. in diameter. The total heating surface in such a pan is from 270 to 300 sq. ft. Sometimes the coils are wound as cylindrical spirals and placed one above another so as to lie near the wall of the pan. This

localizes the heating and so cuts down the efficiency of evaporation. It is better to distribute the heating surface throughout the milk as much as possible without great sacrifice in ease of washing and cleaning the coils and wall. A flat spiral is better for the distribution of heat, but it renders cleaning much more difficult. The first-mentioned form is the most convenient for washing; if the flat spiral is used, there must be space enough left in the middle for a man to get his arm in to wash both coils and walls. Easy access for cleaning is a prime consideration in the case of all dairy apparatus, and sanitation cannot be sacrificed to cost of construction.

Data in regard to the distribution of heat from coils of various lengths and diameters will be found in Appendix F, page 362.

Smoothness of heating surfaces is one of the most important factors in the construction of heaters for milk. The connections of tubes and coil supports should be smoothed. The coils should be firmly supported, so that the violent boiling may not, by means of the great vibration caused, loosen the tubes and cause leakage. The coils should never extend to a point more than half the height of the pan; and if possible they should be kept lower than this, so that they can be employed during the longest possible portion of the time of evaporation.

The milk inlet is usually placed near the top of the cylinder, where the operator can easily reach it for regulation. The location of the inlet is not important, so long as the operator can control the admission of milk quickly and easily. Whether the inlet should be a valve or a cock is a debatable point. Valves are better adapted to fine regulation than cocks, but cannot be operated so quickly. As quickness is more important than fineness of regulation, the author recommends a well-made cock for the milk inlet. The opening of the inlet pipe is sometimes directed toward the opposite wall. This is poor practice, as it is likely to cause spattering of the milk by sending it against the opposite wall. Some of the splashed milk is more than likely to be carried out into the condenser. The inlet pipe must be bent downward. This may be conveniently effected by having it end in a tee, with a plug loosely screwed into the top arm of the tee. This may be removed for convenient cleaning.

In the middle of the bottom of the pan is a double cock. Its

main purpose is to permit the drawing off of the charge after the operation is finished. It is made double so as to allow a sample to be withdrawn for test while the process is going on. If the pan has a special sampler, a single cock will do, but it is better to have the double one in case of emergency. The cocks should be rather large so as to provide for rapid withdrawal of the charge. If too much time is occupied in drawing off the hot condensed milk, it is liable to be overheated and suffer damage.

Several kinds of samplers are furnished on vacuum pans, but none is perfect, and any such device is just one more thing to leak and get out of order. The double cock offers a satisfactory mode of drawing samples, and the use of special sampling devices is not recommended. When for any reason it is necessary to apply such a device, it should be put as low as possible in the pan, so that a sample can be drawn when the quantity of milk in the pan is small.

Vacuum Evaporator and Encrystallizer.—This is the author's invention, planned to carry through the entire process of manufacturing condensed milk in the vacuum pan, doing away with costly and space-demanding milk coolers. In many cases, milk coolers take more space than any other piece of apparatus used in the process of making condensed milk. The extra cost of the new apparatus is justified by its saving the cost of the coolers and the large space they occupy.

The construction of the vacuum evaporator and encrystallizer is much the same as that of an ordinary vacuum pan, with its jacket, cylinder, dome, and attachments. The difference is in the heating coils. These are replaced by revolving heaters, which, with the jacket, are converted into coolers after the condensing process is finished. The milk is not taken from the pan until it is properly cooled and crystals are properly formed; therefore, it does not come into contact with the outside air. Since the pan is closed, and the cooling may be done under vacuum if desired, there is no chance of bacterial contamination during the cooling process. This is especially advantageous during the fly season. The accompanying plan shows in detail the construction of the first experimental pan, made at the Hokkaido Imperial University. Figure 33 is from a photograph of the pan as it is installed in the dairy laboratory of the University.

Figure 33 shows the general plan of the pan. In the figure, 1 is the cylinder, made of rolled copper sheet with welded connections, insulated with asbestos to prevent radiation of heat. The dome, 2, is also of sheet copper, conical in shape. The frame on the manhole, of cast gun-metal, riveted to the dome, is 3, and 4 is the manhole cover, also of cast gun-metal. The eye-glass, 5, permits the operator to observe the condition of the boiling and cooling milk. Cast gun-metal is the material of the ell, 6, through which the vapor flows to the iron pipe, 7, and so to the condenser 8, which is made of sheet iron. Water is conveyed to the condenser through the pipe, 9, and the sprayer, 10; then to the vacuum pump through the pipe, 11. The blow-cock is 12; 13 is the thermometer; 14, the milk-inlet pipe; and 15, the pipe leading to and from the double cock, 16. The steam-inlet pipe is 17, and 18 is the box for steam, coming from the steam pipe, 19, and passing to the steam inlet, 17. The outlet pipe for the water of condensation is 20, communicating with the drain pipe, 21. The heating paddle, 22, has holes, 23, for the free passage of milk. The jacket, 24, has its upper surface of sheet copper and the lower of cast iron. The exhaust pipe, 25, from the vacuum pump, delivers steam to the jacket, a baffle, 27, preventing it from striking the bottom of the pan at one spot only, and also tending to prevent the oil in the exhaust steam from coating the copper bottom of the pan. Steam packings are shown at 28, 30, and 32. The packings are crowded into place by the rings 29 and 31. The spindle, 33, turns on a large steel ball, 35, whose position is regulated by means of the screw, 36. All the fittings of the revolving paddles are supported by the cast-iron base, 34. The revolving outlet pipe is supported by the collar, 37. To this pipe is attached a worm gear, 41, driven by the worm, 38, rotated on the shaft, 39, by the pulley, 40. To prevent leakage of air into the pan, the packings, 42 and 43, are provided. The cast-iron feet of the frame which supports the pan are marked 44.

Figure 35 is an enlarged plan of the construction of steam inlet and drain. Figure 36 shows details of the heating and cooling paddles which revolve in the pan.

Although several improvements, relating chiefly to the packings for the exclusion of air, have suggested themselves since this machine was built, the small machine works well. In order to

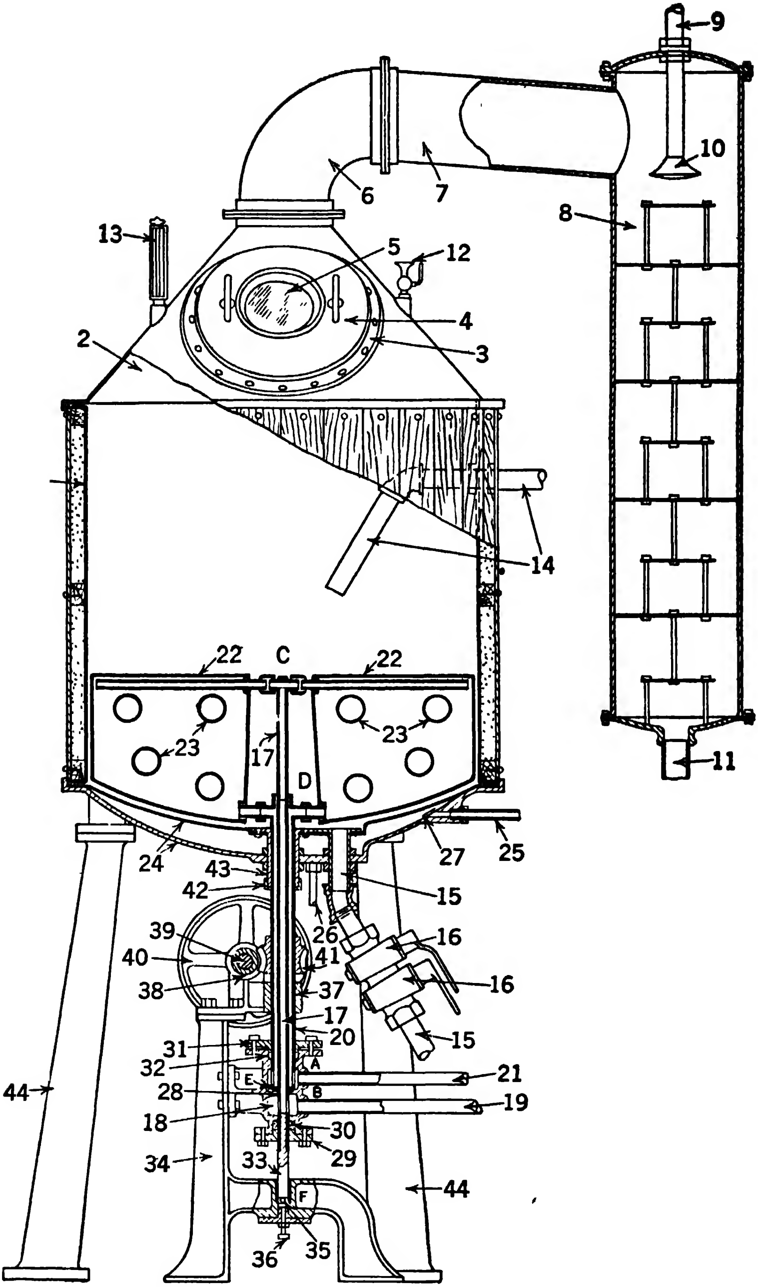


Fig. 33.—Vacuum Evaporator and Encrystallizer.
Elevation and Section.

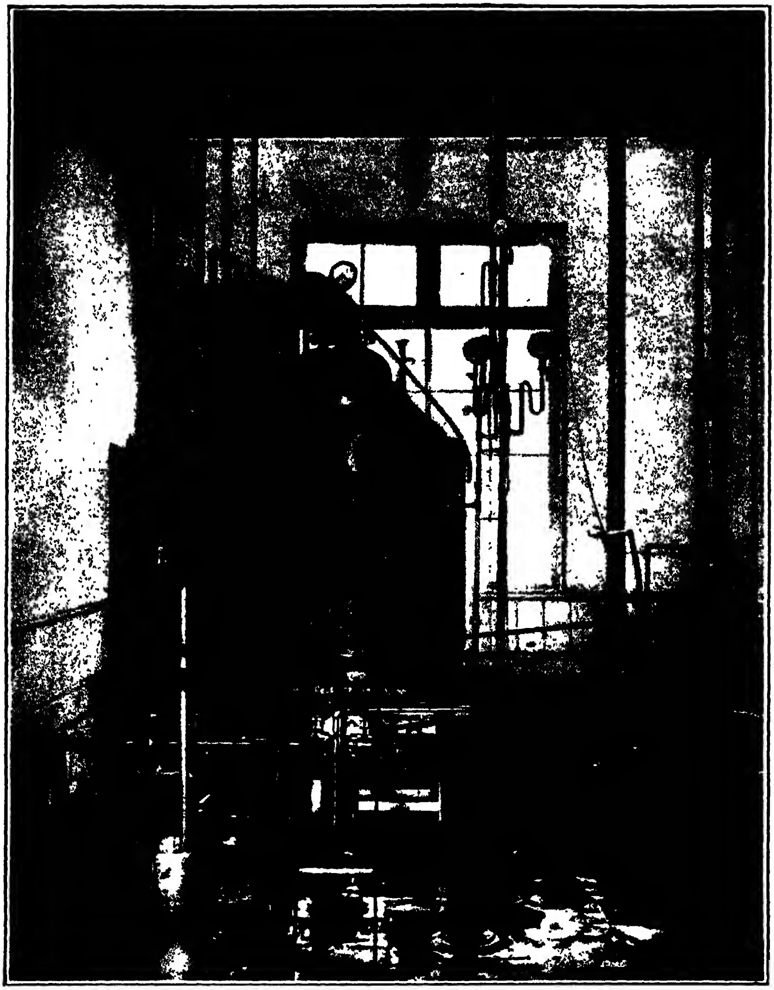


Fig. 34.—Vacuum Evaporator and Encrystallizer.
The Dairy Laboratory, Hokkaido Imperial University, Sapporo.

build a standard-size apparatus, several modifications are necessary. The small pan has one revolving paddle; a large one would have to have the heating coils in sections, for the reasons already given (p. 165). To attach the apparatus for moving the agitators at the bottom would not be practicable in the case of the large pan. The driving gear and steam inlets must both be at the top. Figure 37 shows plans for the 6-ft. pan. The steam pipes entering at the top must be surrounded by a larger pipe and insulated within this. The drainage is from the bottom. The three sections of the agitator are separately connected to the steam supply, as in the ordinary pan with stationary heating coils.

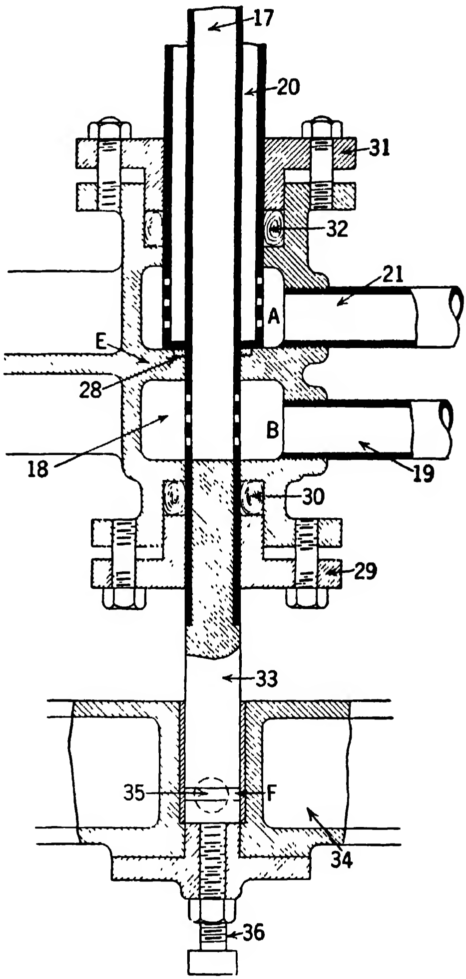


Fig. 35.—Details of Steam Inlet and Drain Outlet.

Condenser.—Several kinds of condensers are used in connection with vacuum pans. They may be classified in two general groups, spray condensers and surface condensers. In surface condensers, the vapors are led through pipes or tubes having a large surface. The cooling water is led in the opposite direction on the outside of the tubes. Such condensers are applicable to the case where the condensed liquid is to be recovered, as when alcohol or some other valuable liquid is concerned, or in the manu-

facture of distilled water. They are both larger and more expensive than spray condensers, and are not used in connection with the ordinary condensed milk vacuum pan.

Spray condensers are of two types, the so-called wet and dry condensers. In the wet condenser, the water of the spray and the vapors coming from the pan flow in the same direction, and are drawn off together, as in the type shown in the figure, page 170. In the dry condenser, the vapor may flow upward and be drawn off by the vacuum pump along with the air at the top of the condenser, while the condensed vapor and the spray water flow downward and are drawn off in another way. This counter-current system is very effective. It is further described below.

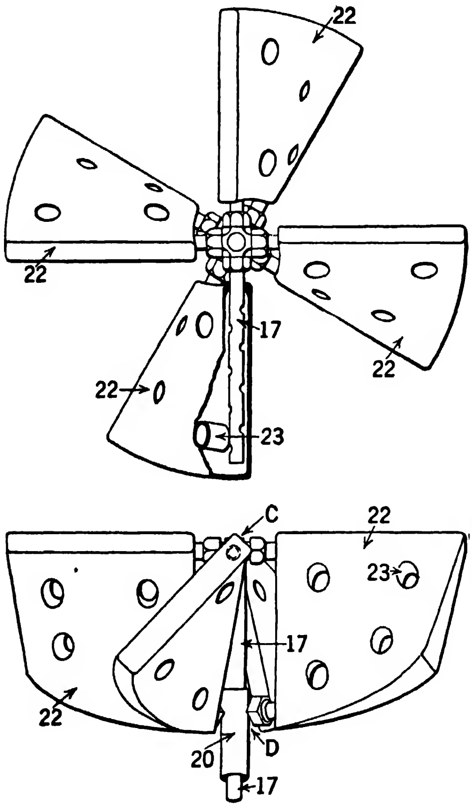


FIG. 36.—DETAILS OF THE HEATING AND COOLING PADDLES.

If a closed vessel is filled with steam, and sufficient cold water added, the steam will be converted into water, and the temperature of the whole quantity of water will be considerably higher than that of the cold water which entered. Besides this warm water, the vessel will now contain, in the space above the water, water vapor and the air which was introduced with the cold water. Because the vapor pressure of warm water is higher than that of cold, the vacuum in the space above the water would not be quite 30 ins. at sea level, and the air further reduces this figure. In spite of these reductions, however, we have a nearly complete vacuum in the pan. In the process of condensing milk, if the

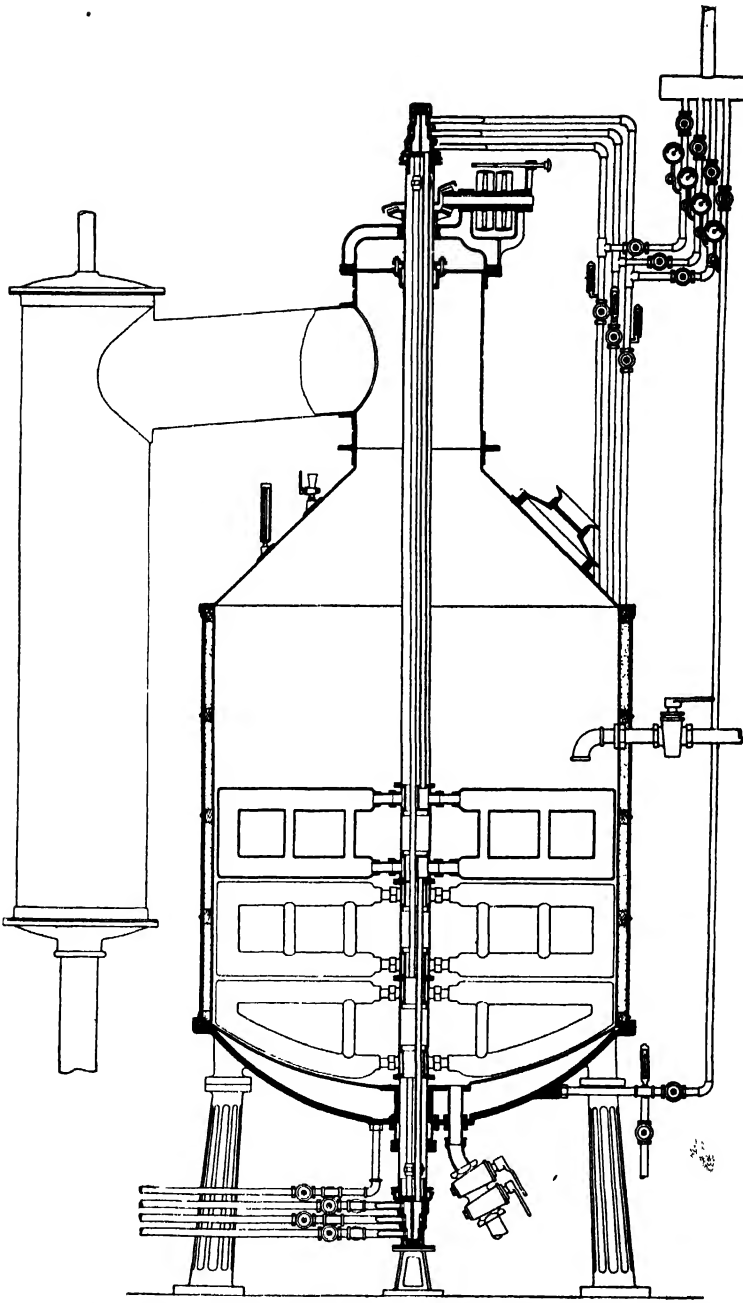


FIG. 37.—PLAN OF 6-FT. VACUUM EVAPORATOR AND ENCRYSTALLIZER.

vacuum pan were perfectly air-tight, it would seem· that an almost perfect vacuum could be produced simply by condensing the vapor as fast as it was formed. Since it would take a very large condenser to hold all the condensing water as well as the water from the condensed steam, it would be necessary to provide a pump of sufficient capacity to remove all of this water, and then we might expect to get an almost absolute vacuum. The trouble is that, with the condenser water and with the fresh milk drawn in, air is continually being introduced, because both the water and the milk contain air dissolved in them. This air gradually accumulates and causes the vacuum to fall. The pump must therefore remove not only the water but also the air as fast as it accumulates. Even then it is not possible to maintain a vacuum of 30 ins., for the vapor continually released by the boiling milk tends to lower the vacuum, since it cannot be instantly removed when such large quantities are all the time being released.

The pressure in the condenser should be as low as possible, so that the difference between that in the pan and in the condenser shall be as high as may be, so as to increase the speed of flow of vapor into the condenser, and therefore to increase the speed of evaporation. Both temperature and pressure differ in different parts of the condenser, but the highest pressure must be lower than that in the pan. The quantity of water required to condense the vapor depends on the weight of vapor to be condensed and on its temperature; also on the temperature of the cooling water and that of the waste water after condensation. It is quite evident that cold water for cooling is very desirable. A mathematical discussion of the problems involved in the condensation will be found in Appendix G, page 364. Roughly, the quantity of condenser water at 60° F. required to condense milk is ten times the weight of the milk condensed. If there is not a sufficient supply of cold water, it may be necessary to cool the water in the air and use it again and again. To cool the condenser for condensing 20,000 lbs. of milk, 30,000 lbs. of water, cooled in the air and used over and over at a minimum temperature of 80° F., will in general be sufficient, if the current of water circulates so as to take the whole 30,000 lbs. through the condenser in fifteen minutes, four hours being required to complete

the batch of milk. This would require a pump of very large capacity.

The diameter of the pipe which conveys the water to the condenser depends on the quantity to be supplied per unit time and on the "head" of the water. It is customary to measure the force urging water to flow, when only gravity is concerned, in feet; that is, when water is flowing through a pipe from a height of 10 ft., it is said to have a head of 10 ft. Water flowing under the influence of suction due to a partial vacuum may be said to have a head equivalent to the partial vacuum, measured in feet of water. If the water is flowing into a condenser from a source on the same level, and there is a vacuum in the condenser of 26 ins. of mercury, equivalent to about 29.5 ft. of water, we may say that the water flows under a head of 29.5 ft. Distances above or below the level of entrance to the condenser must be added to or subtracted from this 29.5 ft. If the source of water is so low that there is no head, the water must be forced up to the condenser.

If it is possible to place the condenser high enough, and if cold water with a good head is available, it is advantageous to install a dry condenser, more properly called a fall-pipe or barometric condenser. In this, the pump carries away only the air and any uncondensed vapor, while the water is carried off from the other channel, which is simply a straight pipe from the bottom of the condenser, ending in a well, called the hot well. Since there is never a perfect vacuum in the condenser, the free length of this pipe will always be less than 34 ft., the height of water supported by the standard atmospheric pressure at a temperature of about 60° F. At a higher temperature, however, both the diminished specific gravity of the water and the higher vapor pressure make the height of column necessary to maintain a given vacuum greater than would otherwise be the case. A total length of 36 ft. for the vertical pipe is sufficient, of which 2 ft. or less may be immersed in the water at the bottom. The water that overflows from the hot well may simply pass to the sewer, except such portion as may be used for boiler supply and other purposes. Figure 38 gives a plan of a condenser similar to the one described.

A is the goose-neck connective pipe from the pan. It should

slant toward the condenser, so as to avoid the danger of splashes of water passing back into the pan. If the pipe is horizontal, there must be a guard, but this hinders the flow of vapor. *B* is the condenser in which the stream of vapor meets the cold water entering by the pipe, *F*. The shelves, *a*, have many small holes in the bottom of each, so that the water falls in a spray, giving the vapor the best opportunity to come in contact with the water. *C* is the condenser pipe, or fall-pipe, about 34 ft. long, *b*, from the bottom of the condenser to the level of the water in the hot well. *D* is the hot well, with drain to the sewer. The height of water, *c*, maintained in the condenser pipe depends on the vacuum in the pan and the temperature of the waste water, as well as on the height of the barometer at the time. Through the pipe, *E*, a pump draws off the air and any uncondensed vapor.

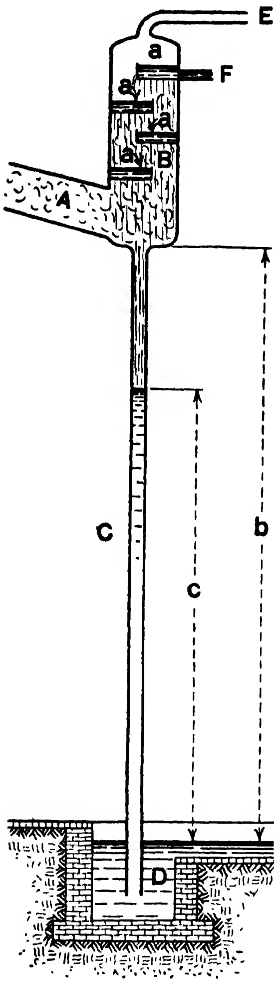


Fig. 38.—Barometric Condenser.

If a high head of water is available at reasonable cost, an ejector condenser can be arranged to advantage, eliminating the pump entirely. For good performance, a good pressure of cold water is absolutely necessary. If the supply water fails or the pressure falls, the effect will be serious, as the breaking of the vacuum in the condenser will at once break that in the pan and probably spoil the whole batch of milk. The ejector is a simple instrument, but to be satisfactory it must be made with the greatest accuracy.

For any form of condenser, an ample supply of water is very important. If the supply in the tank becomes low, a swirl sometimes results, and a hole forms in the middle through which air is

sucked into the condenser. In order to avoid this danger, it is well to have a piece of board floating on the tank, as this prevents the formation of a swirl. The tank should be at least large enough to hold one hour's supply.

Vacuum Pump.—If an ejector condenser is used, no vacuum pump will be needed, but ordinarily it is one of the most important parts of the equipment of a condensery. While this is called a vacuum pump, and is used to produce a vacuum, it really pumps out the waste water and incidentally the air which has been carried in by the milk and cooling water. Such a pump is called a wet pump. The pump used with the barometric condenser is called a dry pump, as it has only to draw air and uncondensed vapor.

An important difference between the wet and the dry pumps is in the construction of their valves. The valves of the wet pump are pieces of rubber, fiber, or metal, opened and shut by the pressure of the air, without mechanical aid. Since water cannot be given so high a velocity in the pump as air, the valves must be larger than those of a dry pump. The speed also must not be too high, from 30 to 50 revolutions per minute being a good range. Experience shows that if the speed of the pump is too high, the vacuum falls, instead of rising as one might expect. This is because the air mixed with the water does not escape properly, a portion of the air remaining in the cylinder, and so cutting down the efficiency of the pump. The water should also be cold or at least not hot. With good performance of the pump, a vacuum of 26 to 27 ins. in the pan may be maintained.

With the barometric condenser, a dry pump may be used. The valves are mechanically operated, the dead air spaces are smaller, and the speed of operation may be greater than with a wet pump.

Operation of the Vacuum Pan.—If one is to operate the vacuum pan successfully, thorough knowledge of it and the connected apparatus is necessary. In preparing for a run, the first thing is to examine all parts of the apparatus. The pan must be clean, and all connections in order. The condenser must be in working order, with the water supply assured. It is important to examine the vacuum pump and make sure of its condition. Care must be taken to have the milk supply so in hand that there will

be sure to be a continuous flow after the boiling starts; as this is essential to a good result. Too much stress cannot be laid on good judgment at every stage of the process.

Steaming the Vacuum Pan.—The first step in operating the vacuum pan is to fill it with steam. This is done both to sterilize it and to secure a high vacuum quickly. The sterilization may be regarded as complete when the temperature has reached 200° F. While the steam is being blown in, the manhole cover should be on, but the blow-cock and the double cock at the bottom should be open. The water of condensation, formed by the steam striking the cold pan, flows out at the bottom, and the air is forced out through the blow-cock, as well as through the cock at the bottom. When the temperature shown on the pan thermometer reaches 200° F., both cocks should be shut and the steam shut off. Then water should be sprayed into the condenser, and the vacuum pump started.

Starting the Vacuum Pump.—Water must be sprayed into the condenser before the vacuum pump is started, because the pump will not work without water. As it goes on, it not only draws the water of condensation and the cooler water, but also the air which was not expelled from the pan by the steam admitted. There will always be a small residue of air left in the pan after it has been steamed, unless the process is long continued and a lot of steam wasted. With the dry pump also, spray water must be started before the pump is set in motion, otherwise steam will be drawn into the pump and will make trouble. If no air is admitted to the pan, and the pump works well (with only a little water spraying into the condenser), the vacuum rises quickly to 25 ins. Higher vacuum comes very slowly, because the remaining small quantity of air keeps on expanding and fills the space, so that the pump draws less and less at each stroke.

Drawing Milk into the Pan.—When the vacuum gauge registers over 25 ins., the milk inlet may be opened fully and the milk sucked in. Since the milk is hot, it will fall to the bottom boiling. The self-boiling milk will soon cover the heating surface of the jacket.

Steam in Jacket.—As soon as this has taken place, the steam should be turned into the jacket, to encourage more vigorous

boiling. Care must be taken not to turn on the steam while any portion of the heating surface is exposed, or the milk will burn fast. It is well also not to turn in too much steam, as too high a pressure is likely to burst the jacket. It is well to use exhaust steam from the pump for the jacket.

Steam in Coils.—As the amount of milk increases, the boiling being continued by heat from the jacket as well as that coming in with the milk, presently the lowest coil will be covered. Steam should then be turned into it, and the increased evaporation will push the vacuum down unless more water is turned into the condenser. So long as the vacuum is maintained, no more water is necessary. To economize water, the temperature of the escaping water may be taken. If the waste water is not more than 5 degrees Fahrenheit cooler than the temperature in the vacuum pan, the condenser is working well. At the beginning of the operation, a difference of 10 degrees is not too much. As the milk valve remains fully open, the second section of coils will presently be covered. Now steam is turned into this, and the cooling water is again regulated. When the last coil is covered, the last steam valve is opened. The evaporation is now at its maximum. The milk inlet is now regulated so as to keep the level of milk in the pan as nearly constant as possible, until the last of the milk is drawn in. If any portion of the heating surfaces is exposed, milk sticks to it, the transfer of heat is hindered by the low conductive power for heat of this film, and, besides, the batch is liable to be injured in flavor and odor.

Degree of Vacuum.—The operator must keep watch on the vacuum gauge. It is necessary to keep up a vacuum of more than 25 ins. When the vacuum falls below this, the temperature increases dangerously. On the other hand, the boiling temperature is much reduced as the vacuum rises. With a vacuum of 28 ins., the milk will boil at a temperature only a little above 100° F., and the rate of evaporation is correspondingly rapid. It would not be advisable to maintain such a high vacuum, however, even if it could be done easily, at least in the first part of the operation. In this first stage, the milk is thin, the evaporation takes place very vigorously, and fine particles are splashed up. These fine particles of milk are carried out with the current of vapor and lost. When the vacuum is higher than 27 ins.,

these phenomena are very noticeable. When this occurs, the inside of the pan becomes somewhat hazy, and when the vacuum rises very high, the haziness is much intensified and the waste water becomes more or less milky. Ordinarily, the waste water from the pump forms a good deal of foam, due to the air carried with the water, but the bubbles disappear at once. If, however, any milk is mixed with the water, some of the bubbles will keep their shape for some time, the number and size of the bubbles depending on the amount of milk in the water. Although the water is apparently clear, any foaming is a sign of milk going over. This is the most delicate test for escaping milk. It is therefore well, if possible, to arrange the waste-water discharge so that it will be in sight of the operator.

Height of Splashes.—When milk is rapidly boiling, both larger and finer drops are thrown up above the surface. These may then be carried by the ascending current of vapor, thrown out of the pan, and lost. Three factors influence the motion of the drops: the velocity with which they are projected upward by the boiling liquid, the downward pull of gravity, and the upward push of the current of vapor rising from the milk. The effect of this push of the vapor is larger in proportion on smaller drops, and the effect on drops of a given size is less in proportion to their weight. The thicker milk in the later stages forms fewer small drops, and the drops are heavier, so that the danger of loss is much less in the later stages of the process. A further discussion of this matter may be found in Appendix H, page 366. Somewhat higher vacuum during the latter part of the process is an advantage.

Relation of Vacuum to Temperature.—If the thermometer and the vacuum gauge are both correct, the readings of the two should have a definite relation to each other, so that one may be used to check the other. The operator should not rely on the vacuum gauge alone but should also read the thermometer; if they do not agree reasonably well, attention must be given to the cause.

The author has made thousands of observations on both temperature and vacuum. The average of all readings of vacuum is 25.85 ins., and of all readings of temperature 128° F., which is a little higher than that indicated by the standard tables for the

boiling point of water at the vacuum named. The temperature actually recorded is always a little higher than the theoretical. The relation of the vacuum to the temperature as registered in the space above the liquid in the vacuum pan is not the same as in the case of water under reduced pressure. The relations found under actual factory conditions are as follows:

RELATION OF TEMPERATURE TO VACUUM UNDER FACTORY CONDITIONS

Vacuum, Inches	Temperature, Degrees F.
22 73	143.2
23 54	137.1
24 52	131.7
25.43	128 6
26 68	127.0
27 28	125 6

RELATION OF THE TEMPERATURE OF VAPOR SPACE TO TEMPERATURE OF BOILING MILK IN VACUUM PAN

Temperature of Vapor	Temperature of Milk	Difference
124 14	130 10	5 96
126 32	132 22	5 90
127 37	131 68	4.31
128 49	133 42	4 93
129 39	133 32	3.95
130 40	133 83	3 44
131 40	134 21	2.81
132 48	136 44	3 97
133 62	137 12	3 50
134 31	138.16	3.85
135 47	138.38	2.85
136 31	138 91	2.60
137 67	140.36	2 69
138.59	141.22	2.63
139.40	141 70	2.30
142 04	145 07	3 03

The temperature difference between the vapor and the boiling milk is greater at a low temperature and a high vacuum. The general average is 4.31° F. The higher difference for the higher vacuum does not prove that the vacuum is responsible for the difference. The higher vacuum comes toward the end of the process, when the milk is thick and its temperature rises rapidly. The

thick milk does not circulate readily, and so it is likely to be overheated, thus accounting for a part of the difference.

Relation of Vacuum to Rate of Evaporation.—Rapid evaporation of water from the milk at a low temperature is the ideal condition in making condensed milk. The relation of degree of vacuum to temperature has been discussed. We shall now examine the effect of the degree of vacuum on the rate of evaporation. It would seem that in the last analysis the amount of heat actually applied to the boiling milk is the main factor in rate of evaporation. A large vacuum pan with a large heating surface will evaporate more rapidly at a low vacuum than a smaller pan with a higher vacuum. Some results with a 4.5-ft. pan are given in the table:

RELATION OF DEGREE OF VACUUM TO RATE OF EVAPORATION

Average Vacuum, Ins.	Maximum Vacuum, Ins.	Minimum Vacuum, Ins.	Milk Fat in Milk, Per Cent	Time per 1000 Lbs., Minutes	Keeping Quality	
					Incub., Weeks	Aging, Years
24.71	26 83	24 25	3 22	31	9 00	1.66
25 60	26 95	24 90	3 29	32	9 66	1.60
26.67	28 23	25.81	3 37	42	9 37	1.96
27.27	28.27	26 58	3 48	38	9 10	1.91

Contrary to expectation, these data indicate that the time required for the evaporation of 1000 lbs. of water was somewhat shorter in the case of the lower vacuum than in that of the higher. This discrepancy is the result of manipulating the steam in the steam coils. Sometimes the original data indicate that the vacuum was sacrificed by high steam pressure applied to the coils. Naturally, much evaporation takes place and the vacuum falls because of increased vapor pressure in the pan. Therefore, it seems that the vacuum cannot be the determining factor in the rate of evaporation, although, other conditions being the same, evaporation will be more rapid in a higher vacuum. Even then, if the application of heat is the same, in higher vacuum in one case and lower in the other, the rate of evaporation will not differ much in the two cases.

Regulation of Steam Pressure in Heating Apparatus.—The operator should always keep an eye on the condition of the boiling milk in the pan; it must be boiling vigorously all the time. Too much foam is a sign of poor boiling. This may be due to various causes, but the chief one is the condition of the heat supply. An inexperienced operator might easily suppose that foaming was caused by too much heat, but exactly the opposite is often the case. Vigorous boiling breaks up foam, while slow boiling encourages its formation. In most cases where the milk foams badly, more steam should be turned on. If the vacuum is high and the temperature and the steam pressure are both rather low, more steam is the indicated remedy.

If the pan foams badly when the steam pressure is high, the drain pipes should be examined. If steam is escaping with the water of condensation, we have a case of foaming due to imperfect heating from a different cause. Heat enough is passing into the coils and jacket, but it cannot be communicated freely to the milk because the heating surfaces are coated and their conductivity reduced. In such a case it may be necessary to empty the pan, clean off the burned-on milk, and begin anew. Otherwise, not only will the time of evaporation be long, but the quality of the product, especially as to keeping, will be poor. Vacuum from 26 to 27 ins., temperature from 125° to 130° F., and temperature of the drain water not very different from that of the pan—these form a set of conditions which suggest more steam, so long as none runs out the drain with the waste. Steam issuing from the waste is a bad indication, denoting not only waste steam but bad working conditions from one cause or another.

Some authorities object to applying more than 25 lbs. pressure of steam to the coils and jacket, for fear of injury to the quality of the condensed milk. The author's experience does not bear out this view. It is true that the heat applied during boiling is one of the most important of the many factors which go to make up a good product, and also that improper heating is disastrous, and that no more heat than necessary should be applied. But so long as the boiling is very vigorous and the vacuum is well maintained, it is all right to apply even more than 30 lbs. of steam. The author has made very good condensed milk with more than 30 lbs. of steam on the coils and jacket. Good judg-

ment is more necessary than mere pressures registered on the steam gauge. If the judgment of the operator is poor, bad results will be obtained even with very low steam pressures. The requisite steam pressure varies with different vacuum pans, so that no fixed rule can be given. The same number of pounds of steam per minute flowing through longer and shorter coils will give different pressures. With longer coils the pressure will be less. It is the author's opinion that, so long as the temperature and vacuum are within proper limits, it is well to increase the steam and so finish the operation more quickly, because the keeping quality of the product depends on the time occupied in evaporating. A little of the vacuum may even be sacrificed to good advantage, if by this means the speed of evaporation can be increased. The table gives some results obtained under factory conditions.

Relation of Rapidity of Condensation to the Keeping Quality of Condensed Milk, and Factors Influencing the Rapidity

Time per 1000 Lbs., Minutes	Vacuum, Ins.	Steam Pressure of			Keeping Quality	
		Jacket, Lbs.	Lower Coil, Lbs.	Upper Coil, Lbs.	Incub., Weeks	Aging, Years
29	26.16	22.81	30.98	27.42	10.00	2.00
31	26.93	20.67	28.42	22.07	9.55	1.83
33	26.58	20.82	27.70	18.10	8.57	1.48
36	26.97	22.03	29.33	15.36	8.46	1.63
38	26.95	21.86	28.53	11.24	6.66	1.16
40	25.96	19.73	21.21	10.68	4.00	1.50

The vacuum is fairly constant, while the higher steam pressures correspond to shorter times, and the striking feature is the greater keeping time which results from increased speed of manufacture. It is quite clear that in planning a vacuum pan it is very important to provide for a large heating surface so as to cut down the time required for evaporation.

Amount of Milk.—The amount of milk which can be advantageously condensed in one batch depends largely on the capacity

of the pan, the larger pan, of course, handling more milk. With a given pan, the amount that can be handled depends on the skill with which it is managed. As has been shown, the best keeping quality is obtained by rapid condensation; and, of course, this means the most rapid evaporation. Too much milk for the capacity of the pan may hinder evaporation, but too much milk skillfully managed may be less disadvantageous than too little milk for the capacity of the pan. With too small a quantity of milk, the heating apparatus cannot be utilized to full capacity, because the upper coils will be exposed and cannot be used. As has been mentioned, the heating effect of the coils is much more important than that of the jacket. With a small quantity of milk, much of the work must be done by the jacket. The following table shows the effect of the quantity of milk on the rate of evaporation. Each class represents 100 batches.

Relation of the Amount of Milk to the Rapidity of Condensation

Average Lbs. of Milk to One Batch	Time Required per 100 of Milk, Minutes
2,176	56 65
2,776	44 77
3,211	34.80
3,483	48.15
4,571	33 17
5,528	31 25
6,194	32 47
6,291	32 20
6,867	31.55
8,150	30 70
8,181	20 30*
9,582	27 90
9,909	29.95
12,708	18.80*

These figures, while not entirely consistent, show a clear tendency to increased speed of evaporation with larger batches. All of these batches were evaporated in a 4.5-ft. pan, except those marked with an asterisk, which are from a 6-ft. pan. These two lots show that with a large pan the rate of evaporation is much more rapid. Other things being equal, it is therefore advisable to use the larger pan if the amount of milk to be made up warrants it.

Sudden Cessation of Boiling.—Sometimes the boiling in the pan suddenly stops, and the milk settles in the bottom. This is due to the fall of the vacuum, caused by admission of air from some source to the pan. With the fall of the vacuum, the temperature, of course, rises. The effect of small changes of vacuum on the temperature is slow and inconspicuous, but if there is a large leakage of air quick changes occur. The rate of boiling is much more quickly affected than the temperature. This is one of the reasons why the operator must watch carefully the condition of the boiling milk in the pan. If leakage of air goes on unnoticed for some time and no measures are taken for its correction, the result may be disastrous. In such a case, when boiling is resumed, there will be serious foaming, and hundreds of pounds of milk may be lost.

The source of the leakage may be anywhere about the apparatus, but the most common sources are the milk-supply pipe and the water supply to the condenser. If either water or milk supply runs low, air leakage is apt to occur. Shortage of water supply can be determined by the sound of the pump, and shortage of milk by looking at the terminus of the milk inlet inside the pan. Whatever the source of the air may be, it must be checked. If the air comes through the water pipe, the cock must be closed until the water supply is restored. If the milk supply is at fault, the milk inlet must be stopped. Whatever the trouble, the milk supply should be shut off until normal boiling conditions are restored. All steam valves must be closed until the air leak is stopped, or the milk may burn fast to the pan and coils. After the air leak has been stopped and the vacuum begins to increase, the steam should be turned on again. The amateur operator, who waits at this stage for the vacuum to reach its normal figure before turning any steam on, may see serious foaming when the steam is finally turned on; this may occur so quickly that much milk goes down the sewer very suddenly. This is especially likely to happen if such an accident occurs early in the process. Later, the milk is so heavy that dangerous foaming is less likely to result. Foaming is perhaps best prevented by encouraging vigorous boiling, so that the internal pressure in the bubbles of the foam breaks them.

Causes of Fall in Vacuum.—Many causes operate to cause the vacuum to fall during milk condensing. Air leakage, just mentioned, is only one. Another common cause is found in the pump, the valves of which may get out of order. This results in uneven strokes of the piston and abnormal sounds. Another cause is shortage of spray water, causing incomplete condensation of the vapor. This can be discovered by the temperature of the waste water, which will be too high if the supply is inadequate. An experienced operator can tell from the sound of the pump when the waste water is too hot. Another test is to touch the condenser; if it is too hot there is not enough spray water. Boiling is not stopped in this case, but becomes less vigorous. In the case of air leakage, the boiling stops and the condenser is cooler than usual instead of hotter.

More water is sometimes needed to keep the vacuum from falling; but too much water causes the vacuum to fall, because if more water is sent in than the pump can carry off, the vacuum cannot be maintained. If the spray water is cold, of course, less will be required. Careful judgment must be exercised in regulating the supply. If the vacuum cannot be kept above 25 ins. with the best available regulation of the spray water, less steam must be applied.

Too rapid a supply of milk may cause a fall in the vacuum. This may be due to the too rapid evolution of dissolved air from the fresh milk. It is an advantage to have the milk stand in the sugar well for a time, to allow some of the air to escape before the milk is drawn into the pan. In any case, care must be taken not to draw any foamy milk into the pan, as the large quantity of contained air will cut the vacuum seriously.

Striking.—" To strike it just right " is a colloquial American expression which means, in general, to make a fortunate guess. Hunziker suggests that this is the origin of the term used to denote the method of judging when the process of condensing milk is complete and the batch ready to be withdrawn from the pan. The tests that must be applied are tests of consistency, involving both density and viscosity, and the determination of these qualities is commonly known as " striking."

An experienced operator can determine the end-point of the

process pretty well by the appearance of the boiling milk in the pan as seen through the eye-glass. Toward the end the boiling becomes less and less vigorous. The mode of boiling differs according to the heat applied and the kind of coils. Only experience can tell how a particular pan may be expected to look. At the end-point the milk generally runs from the periphery toward the center of the pan, forming a mass of bubbles 12 or 16 ins. in diameter.

Even the most experienced operator may be mistaken if he relies on boiling conditions alone. It is always advised, and in fact it is the general practice, toward the end of the process, to take out samples from time to time and test them. If the pan has a sampler, it may be used to withdraw a portion for the test; if not, the double cock at the bottom of the pan will serve. When the double cock is used, the first portion drawn should be discarded, and a second draw made for the test.

When the last of the hot milk has been drawn into the pan, the process will be nearly finished. The milk now becomes rapidly thicker, the volume diminishes, and the boiling becomes less vigorous. Presently, live steam begins to flow from the drain pipes from coils and jacket. This indicates that the thickened milk is carrying away the heat from the heating surfaces more and more slowly. The amount of steam should be gradually decreased until it is only about 5 lbs. at the end of the operation. If everything has gone favorably, the batch should be finished in from fifteen to thirty minutes after the last of the milk is drawn in. Therefore, the testing may begin in from ten to twenty minutes after the last milk enters.

Experienced operators always test the striking point by examining the samples macroscopically as to their consistency, and observing their flow. Some take samples in a cup and determine their fluidity with a spoon. This is a good method, but of course requires experience in order to be of value. For the beginner, it is very uncertain, and he must therefore use a hydrometer. The sample may be placed in ice water to be cooled, and the specific gravity taken when it reaches 60° F. This is a very good way to determine the density of the milk, and, if density alone had to be considered, it would be sufficient for determining the striking point of a batch of condensed milk. In practice, however, other

factors besides the mere density enter into the decision, depending on the quality of the original milk and the amount of sucrose added.

Some milk is capable of high concentration, and some is not. A fat-rich milk can be condensed further than a fat-poor sample. The density of the former, however, as registered on the hydrometer, is much less, on account of the fat, whose specific gravity is much less than that of water. More fat in condensed milk, therefore, causes the specific gravity to be less than that of a product made with milk of lower fat content. Sucrose increases the specific gravity considerably. If condensed milk could always be made under exactly the same conditions, the hydrometer test would be very reliable and a fixed density for the striking point could be given. Unfortunately, this cannot be expected for the different batches made at a given factory. The operation of the pan itself has some effect on the striking point. Therefore, good judgment is required to supplement the hydrometer test.

In using the hydrometer, the cooling of the milk to 60° takes time, since it cannot be stirred too vigorously, on account of the danger of incorporating bubbles of air, which causes a low reading. A slow method of determining the striking point has serious disadvantages, for the reason that the milk is condensing in the pan all the time that the test is being made. By the time the test is over, the milk in the pan is different from the sample tested. The longer the time occupied, the greater the difference. The ideal test would be accurate and instantaneous. This is a very difficult combination to get. Sometimes it may be necessary to sacrifice some of the accuracy of the test in the interest of the accuracy of the final result; that is to say, if the test is made a little less accurate and more rapid, it may give a better result than a slower and theoretically more accurate method. To shorten the time of testing, the hydrometer reading may be taken at the temperature of the sample when first withdrawn, thus saving the time required for cooling and also shortening the time required for the hydrometer to come to equilibrium, since the hot milk is more fluid.

In America the Baumé hydrometer is generally used for condensed milk. A special hydrometer, reading directly in specific gravity, may be used to good advantage. Such a one, with a

long, narrow stem, reading from 1.20 to 1.40, is suitable for the purpose. According to Hunziker, canned condensed milk has a specific gravity ranging from 1.28 to 1.30. The author's experience in making sweetened condensed milk from whole milk gave an average density at the striking point of 1.304. With skimmed milk, the figures reached 1.345; and with half-skimmed milk, from 1.321 to 1.333. The average Baumé reading for condensed milk from whole milk should be about 33.5°.

The formula for deducing specific gravity from Baumé readings, for liquids heavier than water, is sp. gr. $= \frac{144.3}{144.3 - B}$, where B is the Baumé reading. The converse formula is

$$B = 144.3 - \frac{144.3}{\text{sp. gr.}}.$$

Hydrometer readings made at temperatures higher than 60° F. will be too low. The temperature of the milk samples, as drawn, varies with the steam pressure and the degree of vacuum. Ordinarily, the temperature ranges from 110° to 120° in the testing cylinder. Hydrometer readings for milk ready to be struck will be about 1.28 or 1.29 at those temperatures, corresponding to about 32° Baumé.

Beginners are advised to test the striking point either with a special hydrometer reading directly in specific gravity, or with a Baumé hydrometer at the temperature as drawn from the pan, and at the same time to gain experience in judging the consistency of the milk by the resistance which it offers when the hydrometer is pushed into it, and by the way it flows off the instrument when the latter is lifted out. Experience enables one to judge the consistency quite well by these means, provided the diameter of the hydrometer and of the testing cylinder are always the same. When the density seems high as the instrument is placed in the milk, it is well to shut off the steam without waiting for the hydrometer to adjust itself in the milk. Then the reading may be taken. If it is still low, and the flow of milk from the hydrometer is too rapid, dropping instead of stringing, the steam may again be applied to finish the condensation. This is a much safer way than to wait until the hydrometer has been adjusted and

read. By that time the condensation may have gone too far and the product may have been injured.

There are many other methods of determining the striking point, but none is perfect. Almost any method serves well if supplemented by experience and good judgment.

When the proper striking point is reached, all the valves admitting steam to the vacuum pan should be closed. Then the spray-water valves should be closed and the blow-cock opened. The pump should be stopped after water has ceased to run from its discharge pipe. When the vacuum is broken, the manhole cover may be taken off and the pump worked slowly for a time to draw off the hot air from the pan. The condensed milk is then drawn from the outlet cock at the bottom into cooling containers, for further treatment.

If, however, a combined vacuum evaporator and encrystallizer is used, after the striking point has been reached and the steam shut off, cold water is turned in instead, and the machine run as before except that only enough spray water is used to enable the pump to work properly.

THE COOLING ROOM

The condensed milk, having been drawn into proper receptacles, is now taken to the cooling room for agitation and cooling. This process is usually called cooling, and it is supposed by many to have no other object than to cool the product. The author's experience indicates that there are other important purposes. A proper understanding of this matter is essential to the successful manufacture of sweetened condensed milk. A very important purpose of the cooling process is the proper crystallization of the milk sugar. If cooling were the only purpose, it would be a very simple and easy matter. If cold water is circulated about the milk containers, the milk is quickly cooled, but next day the condensed milk will be grainy, or "sandy," and will be unmarketable. The process must be conducted in such a manner as to insure a smooth product, or all the care lavished on the earlier steps of manufacture goes for nothing.

The quality of sweetened condensed milk is often judged by the presence or absence of crystals. To say that one sample is

bad because it has crystals, and another good because it has none, is to make the mistake of an amateur; but, since there are more amateurs than experts, and these amateurs are the consumers, it is necessary to produce such condensed milk as will satisfy the whole public. Manufacturers used to try, without any real result, to produce condensed milk without crystals. Authorities on the manufacture of condensed milk generally say that it is necessary to prevent "excessive crystallization."

Sweetened condensed milk always contains crystals, as may be seen by examination under the microscope. The size of the crystals varies, however. When large ones are present, they may be felt; a product containing such crystals is called sandy or grainy, and people say that it has crystals. When, on the other hand, the crystals are so fine that they cannot be felt, the milk is declared to have no crystals. The thing to be done, therefore, is to encourage the formation of fine crystals.

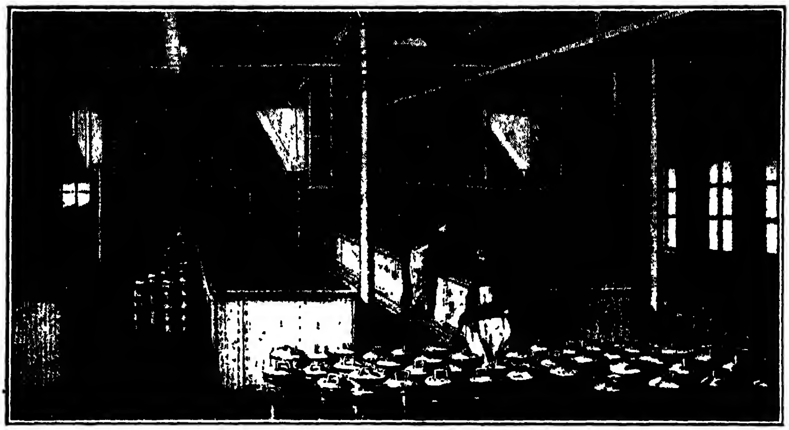
Milk sugar, as has been mentioned, is sparingly soluble in water, 1 part of milk sugar dissolving in 2.5 parts of cold water. The milk sugar may remain for a time in a state of supersaturation. Sweetened condensed milk has about 13 per cent of milk sugar and 25 per cent of water; that is, there is not enough water to keep the milk sugar in solution.

In general, large crystals form in an undisturbed liquid when conditions (as to temperature, evaporation, etc.) are such as to favor slow crystallization. Therefore, in order to get fine crystals in condensed milk, it must be agitated and the temperature must be controlled, so as to secure rapid formation of crystals after they begin to form. As to temperature, it has been found best to keep the cooling water not much below the temperature of the milk at the beginning. Finer crystals may be formed if the water is at 90° F. the first hour than if it is at 60° or 70°. Too sudden cooling results in coarser crystals unless the agitation is very vigorous. When all these facts are considered, it appears that the word "cooling" is not an appropriate name for this process. It is better to call it "encrystallization."

If the operator understands the principle involved and regulates the process accordingly, it is not very difficult to get good results; and certainly there is no secret about it. Too much has been made of the idea of secrecy in connection with the manufac-

ture of condensed milk. Some factories still claim to possess valuable secrets and close their doors to outsiders. Such practices are rapidly passing out of date as the scientific method wins general support. The present tendency is toward coöperation, which is the road to real progress.

The usual method of cooling is to put the milk in cylindrical receptacles of 10 to 15 gallons capacity. These are placed on revolving gearings in the cooling tank. The smallest tank for factory use has a capacity of six cans, while some hold as many as forty-eight. Large coolers are rather difficult to regulate. The



Courtesy of Nestlé and Anglo-Swiss Condensed Milk Co.

Fig. 39.—Cooling Room.

This long-used method, with revolving cans and fixed paddles, is efficient and satisfactory.

tank is filled with water at a proper temperature, and the cans put in place with one or two wooden paddles projecting into each can. These are attached to cross-bars above the tank. The paddles should fit closely against the sides of the milk containers, to rub the condensed milk against the side of the can. This is very necessary for the proper formation of crystals in the milk. The more thorough this rubbing effect, the more rapidly will the crystals form, and consequently the finer they will be.

To get this close fit, the paddles must be straight and the sides of the cans straight and smooth. In practice new cans and paddles do not work so well as used ones. Wear adjusts cans

and paddles to each other, and it is well to number the cans so that they will always be placed in the same position in the tank and so take the same paddles. When the paddles have been placed, power is connected to a pulley outside the tank, turning a shaft inside which in turn rotates the gears carrying the cans. The stationary paddles thus stir and rub the milk, promoting the formation of small crystals. After running about thirty minutes, the milk should be examined under a microscope. If conditions are right, crystals may already be appearing. If so, fine crystals are sure to be obtained. If several crystals are seen in a field, cold water is turned on and the real cooling begun. This may be continued for two to two and a half hours, to a temperature of about 70° F., the crystallization being regulated, from time to time during cooling, by tests under the microscope.

If no crystals are observed at the first examination, it should be repeated every five or ten minutes. If no crystals appear after forty-five minutes, or one hour of agitation, crystallization must be encouraged by some means, or coarse crystals will result. To encourage crystallization, more rubbing may be effective, or sometimes seeding may be resorted to. For this purpose, fine powdered lactose may be used; or, where this is not available, condensed milk with fine crystals may be added. The lactose used for seeding must be very fine or it may cause sandiness. A very small quantity of this seeding sugar is sufficient. The milk or sugar for seeding should be examined under the microscope to secure the best results.

In the best-finished product the crystals are of even size. Often microscopic examination shows a variety of sizes. Such milk is apt to be sandy. The early appearance of crystals is not the only important point; they should be very numerous. It is better to have a multitude of crystals after an hour of agitation than a few at thirty minutes with no increase in number for a long time. In the former case the crystals at the end of the process will be even-sized and fine, while in the latter the first-formed crystals will grow to large size and cause grittiness.

When a sample examined under the microscope shows the field full of crystals, the agitation may be stopped. If crystals have appeared in abundance within an hour, the cooling to 70° may be completed in two to two and a half hours. If crystals do

not appear until later, the whole time required will be greater. The longer the time, the finer and surer the crystallization. Three and one-half to four hours will usually be enough.

This method of cooling and agitation is one of the oldest, and is very efficient and easily controlled. There are two objections to it, however: it occupies too much space, and the milk is exposed for a long time to contamination. To eliminate these objections, many devices have been invented. Most of these neglect the crystallizing part of the process. No machine for cooling that does not provide for control of crystallization is suitable for use in making sweetened condensed milk.

A large cooling tank to hold an entire batch, with a cooling agitator inside, is often used. Such apparatus does the cooling well, but, unless seeding is resorted to, the crystallization is uncertain. With properly conducted seeding, this method is superior to the old one.

In some factories, cooling tubes are used. Such apparatus is efficient as a cooler, but the same uncertainty about crystallization exists as in the tank coolers. Moreover, the great amount of surface occasions much loss of condensed milk, and the tubes are difficult to clean. It is said that in some factories these tubes are seldom cleaned, being used day after day without washing. Better crystallization is obtained when this is done, as the adhering condensed milk seeds the new batch. This method is objectionable from the standpoint of cleanliness, however. All these new cooling machines are more or less hit-or-miss methods with regard to the crystallization of lactose, unless seeding is practiced.

The vacuum evaporator and encrystallizer previously described, pages 167 to 171, is intended to eliminate the coolers and, at the same time, to insure better crystallization of lactose. The slight experience which the author has had since the installation of this machine in his laboratory shows that it has the following advantages and disadvantages: The advantages are that it (1) eliminates expensive coolers, (2) saves space in the factory, (3) eliminates contamination during encrystallization, (4) saves the time spent in pouring out for cooling, since the cooling begins at once when the striking point is reached, (5) prevents the incorporation of air into the milk, (6) makes possible

more vigorous agitation (because of the removal of the danger of air incorporation), and hence more rapid crystallization, and (7) minimizes loss of condensed milk from sticking to utensils. The disadvantages are that (1) since condensing and cooling are done in the same pan, this pan cannot be used over and over again the same day, (2) the original cost of the pan is greater, and (3) the packing for excluding air at the revolving pipe bearings requires rather complicated fittings.

The first disadvantage affects manufacturers who are making two or three batches a day with one pan. The vacuum pan is the most costly piece of apparatus in the plant, and the manufacturer desires to make the best use of it. As already stated, in order to get the best results, larger-capacity apparatus is superior to smaller. While the original cost of the larger pan is greater, it pays in the end. There is a saving of heat and labor in making one large batch rather than several small ones, and the product gains in uniformity.

Where it is impossible to make a day's product in one batch because of delivery of milk at different times, it is sometimes advisable to make more than one batch, if a reasonable amount of milk can be had for each batch, which should not be less than 10,000 lbs. If the seeding method of promoting crystallization is used with this method, the process can be completed quickly, and it is possible to use the pan twice in one day.

The second disadvantage may be more than offset by the elimination of the cost of special coolers; the third may be minimized by proper application of the water-packing method as a means of excluding air. It would appear that such a machine or one still further improved may be a step in advance in the industry.

THE FILLING ROOM

After the cooling and crystallization of the milk sugar are complete, it is best to fill the condensed milk into proper containers for marketing as soon as possible. If it stands too long, evaporation of water from the surface causes a skin or crust to form, which means loss. Also, standing means exposure to contamination. When, however, the ordinary coolers are used, a considerable

quantity of air bubbles is incorporated in the milk, and the cooled milk should stand long enough for this air to rise to the surface so that it may be skimmed off. This is rather important, for though the milk is preserved with sucrose, too much air in the can permits the growth of certain bacteria and molds in or on the milk.

Sweetened condensed milk is usually packed in tin cans of 14 or 16 oz. capacity. The kind sold to confectioners, much of which is made from skimmed, or half-skimmed, milk, is packed in larger tins of about 50 lbs. capacity, and sometimes in wooden barrels. Most of the sweetened product is packed in small cans, which were formerly nearly all of 16 oz. capacity. When competition became keen, some factories started to put out a 14-oz. can at a lower price. Since the World War, the use of 14-oz. cans has become general.

The filling holes of the cans are usually $\frac{3}{8}$ or $\frac{1}{2}$ in. in diameter. Smaller holes are better than larger ones where the sealing is done with solder, but very small holes are not advisable as they make the filling slow and difficult. The viscous material, as it runs in, piles up in the center, and if the can stands still the top of the pile stops the hole and the can seems full when there is still a considerable air space around its periphery. A rotary motion imparted to the can causes the milk to flow out to the edges under the influence of centrifugal force, and thus it is possible to fill the can quite full.

In small factories the filling is done by hand. This is a very good method, if skillful and attentive operatives are available. In larger factories the filling is usually done by machinery. There are several automatic fillers on the market. If properly used, they all do good work. The chief difficulty is to get the cans completely filled. For this reason, machine filling is often supplemented by hand work, which is used for putting in the last portion. The automatic machine is connected to a milk reservoir, and a measured quantity of milk is pumped into each can. Sometimes the filler is connected directly to the bottom of the cooler. The advantage of this is that it eliminates some of the loss due to condensed milk sticking to all the vessels used. If no reservoir is used, there is one vessel less to become coated with a layer of milk which has to be washed off and lost.

The filled cans should be sealed at once. This was formerly done entirely by soldering. Care must be taken not to allow any soldering flux to get into the can. The best and most harmless soldering flux for this work is a solution of resin in alcohol. The alcohol evaporates and leaves a thin film of resin adhering to the tin. Powdered resin is sometimes used, but it is not very satisfactory. An acid flux must not be used.

The solder should be of the best quality and should contain not less than 50 per cent tin. In some countries the limit of lead in solders used for food containers is placed at 10 per cent. The temperature of the copper is important in soldering. If the copper is not hot enough, it is impossible to do smooth work; while if it is too hot, the milk may blow out or even burn near the soldered spot. A quick motion is desirable, so as not to give time for the milk and air in the can to heat. A hotter tool requires less solder. The following figures are taken from the author's notes on factory experience in making and sealing cans. They are for a case of four dozen cans. For soldering the body, 0.055 lb. of solder was required; for the top and bottom, 0.366 lb.; and for sealing, 0.107 lb. These figures are for hand-made cans.

A skillful solderer uses less solder and makes fewer leakers than an unskillful one. In smaller factories the cans are either made by hand or bought from can manufacturers. If ready-made cans are procurable near by at a reasonable price, it is better for the smaller factories to buy them than to make them by hand, as they can usually be bought for less than it would cost to make them. It is said that if the daily output of a factory exceeds ten or fifteen thousand cans, a small automatic can machine may be installed with profit.

While soldering is no doubt a very good method of securing a perfect seal, many difficulties are encountered in practice. To avoid the use of solder, so-called sanitary cans are sometimes used. This is a very good method, and a perfect seal can be secured by it, but it is more expensive than soldering. Other solderless seals are the "Gebee" and the "McDonald." These are also very good, but a perfect seal is less easily secured with them than with the former two.

The sealed cans are conveyed to the store room for labeling and packing. They may be transferred by automatic conveyors

from the filling room to the sealing room, and finally to the store room, where they may be delivered to an automatic labeling machine. The cans are usually packed in cases of four dozen, and the condensed milk is then ready for the market.

Sanitation of Filling Room.—The filling room should be isolated from the other rooms, especially from that in which the soldering is done. The filling room must be kept perfectly clean, to avoid various sorts of contamination which cause defective cans. The "buttons" which occur in canned milk are the most common defect. They are due to the growth of molds in the air space of the can. Mold spores are killed in the preheating, and usually there are none in the condensed milk as it comes from

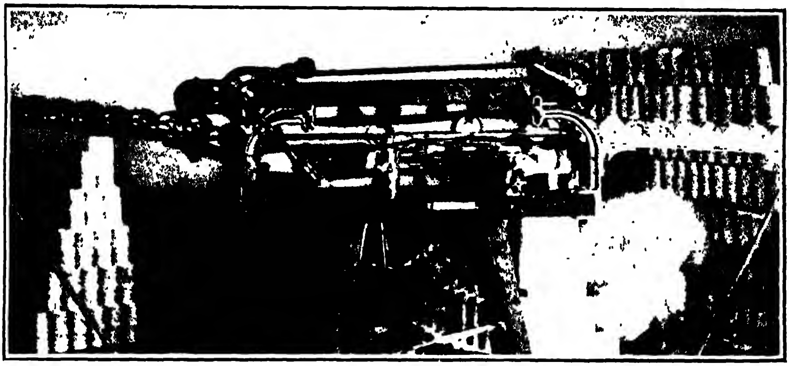


FIG. 40.—AUTOMATIC LABELING MACHINE.

The canned milk may be conveyed automatically from the filling room through the sealing room to the labeling machine.

the vacuum pan. Contamination takes place after the withdrawal of the milk from the pan. The two chances for contamination are in cooling and in filling. The cooling room also should therefore be kept perfectly sanitary. For that matter, the whole factory ought to be scrupulously clean. Large covered coolers minimize the danger of contamination in the cooling process, and if the vacuum evaporator and encrystallizer is used the danger is entirely removed. The methods of filling that are in use all involve risk of contamination, and for that reason the filling room should be guarded with special care.

The reason for this special care lies largely in the presence in

air of living organisms which are continually falling if the air is at rest. Mold spores and many species of bacteria are to be found in the air of almost any room in which people are working, their numbers being in proportion to the number of people. Investigations made in the laboratory at Westminster by Messrs. Rideal lead to the conclusion that there are from 20 to 40 organisms per cubic foot. The rate of fall is very slow, so that the number alighting on a square foot per hour varies from 100 to 800. Another investigation, by Winslow and Browne, showed figures ranging from 50 to 100 organisms, capable of developing at 20° C., per cubic foot, for outdoor air in a suburban district. The number developing at 37° C. (98° F.) was about half as great. The air of a city street showed somewhat higher numbers, while that of factories was still higher, and in some offices as many as 700 per cubic foot, growing at 20° C., were found

Disinfection of Air and Room.—When a room is infected with microörganisms it must be disinfected, which is not very convenient. It is better to keep the room in a clean condition than to have to disinfect it. With the best of care, however, a room will sometimes become infected with organisms deleterious to condensed milk, and in such a case a thorough disinfection is necessary.

Heat.—The direct application of heat to the disinfection of a room is not practicable.

Washing with Water, with or without Disinfectants.—Numerous kinds of apparatus have been designed. Screens of vertical cords and horizontal copper wires, over which water trickles, are useful in settling the dust out of the air. This does not kill organisms, but clarifies the air, and may be practiced before starting to fill the cans with condensed milk, especially if any dust has formed in the room.

Air Filters.—Cotton-wool strainers are sometimes used to strain the air coming into the room. This is no doubt an efficient method, but takes much power and is hardly practicable for factories. Asbestos filters and hydrogen peroxide filtering methods have been proposed for air purification. All these may be applicable on a small scale, as for certain rooms in hospitals, but are not suitable for factories.

Sterilizing the Air and Room by Chemical Means.—The most practical and efficient method of disinfecting polluted air and rooms is the application of a germicidal gas, such as formaldeyhde, sulphur dioxide, or ozone. Of these, formaldehyde is the most frequently used. Good results are obtained by fumigating the room with formaldehyde gas. If only the walls and ceilings need to be disinfected, they may be washed with a dilute solution of formaldehyde.

CHAPTER IV

UNSWEETENED CONDENSED MILK

The earliest real success in preserving milk was in the form of sweetened condensed milk, and the term "condensed milk" is generally understood to mean that variety. In recent years the use of canned milk in tea, coffee, cocoa, and other drinks, and of "bulk milk" by confectioners, bakers, and ice cream manufacturers, has increased greatly, and now the quantity of unsweetened condensed milk made far exceeds that of the sweetened kind.

Hunziker distinguishes three classes of unsweetened condensed milk: evaporated milk, plain condensed bulk milk, and concentrated milk. The first differs from the other two in concentration, uses, and method of manufacture. The second and third are similar in concentration and uses, but are made by different processes. There are not, however, just two methods, but many; so that it is perhaps better to make two classes instead of three, namely: evaporated milk, or unsweetened canned milk; and plain condensed bulk milk, or concentrated milk.

Evaporated Milk.—Evaporated milk, or unsweetened canned milk, is cow's milk condensed by evaporation *in vacuo* in the ratio of about 2 to $2\frac{1}{2}$ parts of fresh milk to 1 part of evaporated milk. It is canned, hermetically sealed, and sterilized by steam under pressure. While its constitution is different from that of cream, it resembles thin cream in consistency and appearance, and is often used instead of cream in coffee, tea, etc. It is marketed in cans varying in size from 4 oz. to 1 gallon, a commonly used size being 16 oz. This product is destined almost wholly for family consumption. It will keep almost indefinitely, but, like most other foods, is best when fresh.

Plain Condensed Bulk Milk.—This product is cow's milk condensed by evaporation, either *in vacuo* or under atmospheric

pressure, in the ratio of about 3 or 4 parts of fresh milk to 1 part of condensed milk. It is usually sold in bulk in 10-gallon cans, but sometimes in milk bottles for family consumption. It is not sterilized and is therefore subject to deterioration on keeping. Its consistency is that of rich cream. Its composition differs according to the kind of milk used, which may be whole, skimmed, or partly skimmed. For direct consumption, the bottled milk is delivered daily in the same way as ordinary milk, and used at once for tea, coffee, or cocoa, and for cooking. Consumption in this way is limited, the great bulk being shipped to ice-cream factories, bakeries, and confectioneries.

EVAPORATED MILK FOR INFANT FEEDING

To meet the difficulties encountered in securing infant food in certain districts of the tropics, the use of evaporated milk has been suggested. William E. Deeks[1] recommends the use of sweetened condensed milk in connection with evaporated milk for making a balanced infant food. Evaporated milk is deficient in heat-supplying nutriment in proportion to muscle builders, especially when it is the wholly or partly skimmed product, while sweetened condensed milk is too high in carbohydrates. Deeks suggests the proportion of 1 part sweetened condensed milk to 3 of evaporated milk. Sometimes cane sugar or dextrimaltose is added to the evaporated milk instead of sweetened condensed milk.

The high temperature applied to evaporated milk in sterilizing destroys some of the vitamins of the original milk, and this renders it generally unsuitable for infant feeding. Vitamin C is very susceptible to heat and is entirely destroyed in the manufacture of evaporated milk. Daniels and Laughlin [2] found that rats made practically no gain in weight and soon died when fed on evaporated milk. They claim, however, that this failure of growth was due to a change in the solubility of the calcium salts in the milk and not to the destruction of vitamins A and B. Hart, Steenbock, and Smith [3] found that unsweetened condensed milk had lost its antiscorbutic value.

[1] Proc., World's Dairy Congress, 1923, p. 149

[2] Jour. Biol. Chem., 1920, 44, 381.

[3] Jour. Biol. Chem., 1919, 38, 305.

Evaporated milk is not intended for infant feeding. It has many disadvantages when used for this purpose. In case it must be used because no more suitable food is available, it should be supplemented by added heat-energy-supplying materials, and with vitamin-supplying substances, especially vitamin C. It is also suggested that one or two teaspoonfuls of lime water be added to each bottle just before feeding.

SUPPLY MILK FOR UNSWEETENED CONDENSED MILK

In the case of unsweetened condensed milk, the necessity for freshness and good quality of the supply milk is even greater than in the case of the sweetened product. While sweetened condensed milk is preserved with a considerable amount of cane sugar, nothing is added to prevent deterioration in the unsweetened product. The keeeping quality of evaporated milk is entirely dependent on sterilization by heat. The supply milk for evaporated milk must be of a quality that will stand the high heat of sterilization after condensing. Only the freshest and best milk can stand such a high temperature. Even the freshest milk is not always suitable for the manufacture of evaporated milk. The individual characteristics of the cow sometimes play an important part in the heat-resisting quality of the milk. Feeds and seasons of the year also have some influence on this quality. The heat resistance of fresh milk depends on its ash composition.

Heat Coagulation of Milk.—The question of the heat coagulation of milk has been discussed by many authorities, and considerable difference of opinion exists as to the probable effect of heat on the chemical and physical properties of the mineral salts of milk. Some claim that heating causes a part of the soluble compounds containing calcium and phosphorus to change to an insoluble condition. Raymond W. Bell [4] studied the effect of heat on the calcium and phosphorus content of milk and reported that there is a loss in the soluble calcium and phosphorus content of skimmed milk due to heat, and that the amount of the loss depends on the temperature to which the milk has been heated. He found that a measurable amount of these substances

[4] Jour. Biol. Chem., Vol. LXIV, No. 2, 1925.

was rendered insoluble at a temperature of 170° F. Results varied with the method of analysis used. By the filtration method, the following results were obtained:

Loss of Soluble Ca Salts and P_2O_5 Due to Heating, Determined by the Pasteur-Chamberland Filter Method

Temperature Maintained for 30 Minutes, F.	Av. Loss of Ca in Filtrate, Per Cent	Av. Loss of P_2O_5 in Filtrate, Per Cent
140°	0.0032	0.0018
150°	0.0011	0.0024
160°	0.0020	0.0016
170°	0 0053	0.0059
180°	0.0039	0 0042

Bell concludes from these data that the changes from soluble to insoluble salts containing Ca and phosphorus, as shown by this method, are small, and that, even for the higher temperatures employed, they but slightly exceed probable experimental error. By the centrifugal method, he obtained the following results:

Loss or Gain of Soluble Ca and P_2O_5 Due to Heat, Determined by Centrifugal Method

Temperature Maintained for 30 Minutes, F.	Average Gain or Loss in Ca		Average Gain or Loss in P_2O_5		Average Gain or Loss, Ash	
	Filtrate, Per Cent	Precipitate, Grams	Filtrate, Per Cent	Precipitate, Grams	Filtrate, Grams	Precipitate, Grams
Raw (check)	+0.88	−0.0126	+1.36	−0.0007	−0.0075	−0.0571
150°	+0.19	−0.0033	−0.78	−0.0009	−0.0035	−0.0389
160°	−0.35	+0.0075	−2 47	+0.0131	−0.0030	+0.0203
170°	−1 59	+0 0072	−2.56	+0.0085	−0.0119	+0.0025
180°	−4 34	+0 0510	−5.68	+0 0033	−0.0240	+0.1149
190°	−7.58	+0 0903	−6 92	+0.0145	−0.0310	+0.2164
200°	−7.04	+0.1003	−8.77	+0 0201	−0.0394	+0.2688
212°	−9.75	+0.1246	−9 53	+0.0218	−0.0419	+0.2954

From these data Bell concludes that with increase in temperature the amounts of soluble calcium salts and P_2O_5 in the

filtrate decrease gradually from the amounts found in the filtrate from the raw skimmed milk from the same source, while the amounts in the precipitate show a steady gain. As the temperature increases, the weight of ash from 100 grams of the filtrate decreases.

Bell's study relates only to the precipitation of calcium salts by heat under atmospheric pressure. The heat coagulation of milk is undoubtedly due, partly at least, to the precipitation of calcium salts, thereby disturbing the ash balance. Ordinarily, fresh milk does not coagulate on heating below the boiling point, unless acid has developed in it or the milk is otherwise abnormal. Prolonged heating under pressure, or condensation of the milk, causes coagulation.

Hugo Henry Sommer[5] conducted a special research on heat coagulation of milk in reference to the manufacture of evaporated milk. He states that the main factor in heat coagulation of evaporated milk is the salt composition of the milk, and he relates this phenomenon to disturbance of the balance between two classes of salts, namely, calcium and magnesium, and the citrates and phosphates. His hypothesis is that there is a balance between these two classes and an excess of either causes coagulation. Sommer states that in evaporated milk, where coagulation is due to an unbalanced condition of the salts, this condition has been found in all cases to be due to an excess of calcium and magnesium. He suggests the use of sodium citrate or disodium phosphate to remedy this trouble. His suggestion has been well received by many evaporated milk manufacturers, and the use of the salts mentioned is widely and successfully practiced.

The detection of heat-coagulable milk is very difficult. It cannot be done by the ordinary tests, nor by the senses of taste and smell. The ordinary acidity test does not reveal this defect. Acid developed in the milk is a usual cause of coagulation at all temperatures, but, as has been shown before (p. 34), the acidity test does not always show developed acid. Even if developed acid were shown by the acidity test, this would not be sufficient for the detection of heat-coagulable milk, for the causes of heat coagulation are many. Low-acid milk often coagulates on

[5] Proc., World's Dairy Congress, Vol. II, pp. 1241, 1923.

heating. Observations were made by Sommer on the titratable acidity and the heat coagulation of eighty-six samples of milk from thirty-one different cows, and no definite relation between acidity and coagulation was found. There were some interesting cases; for instance, the sample of lowest acidity coagulated in one and one-half minutes, while the one with the highest acidity did not coagulate in twenty minutes. It is safe to say that titratable acidity is not the determining factor in the heat coagulation of fresh milk.

It has been suggested that if the titratable acidity does not cause the heat coagulation of fresh milk, the hydrogen-ion concentration may have some relation to the condition of the salts in the milk, and this salt condition may be the cause of the coagulation. Thus the hydrogen-ion concentration might be in some sense a key to the heat resistance of the milk. In order to test this hypothesis, Sommer tested thirty-seven samples of of milk, varying in hydrogen-ion concentration from 6.25 to 6.97. Of these, twenty-three samples coagulated in twenty minutes at 136° C. and fourteen did not coagulate. The average *p*H value of the coagulated samples was 6.71, and of the others, 6.66. This average difference is so slight, and there was such a total lack of consistent relation in the case of individual samples that Sommer concludes there is no traceable relation between the *p*H of milk samples and their resistance to coagulation by heat.

Alcohol Coagulation.--None of the tests so far discussed is a reliable indication of the heat resistance of fresh milk, a quality which is of great importance in the selection of milk for the manufacture of evaporated milk. The alcohol-coagulation test has been suggested, and is already in use by many condenseries and other dairy manufacturing plants in Europe and Japan, and to a limited extent in the United States. It was originally applied in order to determine the sanitary quality of milk. It was then supposed that alcohol coagulation indicated a bacterial change in the milk, producing acid, or rennet-like enzymes. It has been found, however, that this test does not always show the sanitary quality of the milk. Perfectly fresh and clean milk often coagulates with alcohol. The addition of neutral and dibasic salts prevents coagulation (Ayers and Johnson).[6]

[6] U. S. D. A., Bul. No. 202, 1915.

The unreliability of the alcohol test for sanitary quality and freshness of milk caused a dispute between the milk producers and the manufacturers, the latter being at a loss to find a reliable mode of selection. It was suggested that possibly the alcohol coagulation might in some way be correlated with heat coagulation. If this could be done the value of such a test for the selection of milk for the manufacture of evaporated milk would be great.

Dahlberg and Garner[7] studied this problem. The alcohol used was of 75 per cent strength, and equal parts of milk and alcohol were used for the test. The method was found to have promising possibilities. Results are given in the following table:

RELATION OF ALCOHOL COAGULATION OF MILK TO HEAT COAGULATION OF EVAPORATED MILK

No.	Acidity of Milk, Per Cent	Reaction to Alcohol	Solids-not-fat in Evaporated Milk, Per Cent	Condition after Sterilization of Evaporated Milk
1	0.140	−	17 96	No curd
2	0.170	+	17.06	Curdy
3	0.150	−	18 53	No curd
4	0.175	+	18.16	Curdy
5	0.165	−	18.24	No curd
6	0.175	+	18.16	Curdy
7	0.145	−	18 25	No curd
8	0.160	+	17.91	Curdy

In all cases where the alcohol test was positive, the product was curdy; while the evaporated milk made from milk that did not coagulate with alcohol did not coagulate on sterilization. In connection with the alcohol test, Dahlberg and Garner studied its relation to the titratable acidity; they found that there is no direct relation between the two, but that milks that are high in titratable acidity as the result of fermentation will, in the majority of cases, show coagulation with alcohol.

A. G. Benton and H. G. Albery[8] studied the stability of evaporated milk during sterilization, with reference to the hydrogen-

[7] U. S. D. A., Bul. No. 944, 1921.

[8] Jour. Biol. Chem., Vol. LXVIII, No. 2,

ion concentration, the alcohol test, and the addition of specific buffers. They found that the milk of individual cows varies considerably from day to day in *p*H and resistance to heat coagulation, and they regarded each sample as a separate colloidal system. This makes the treatment of low heat-resisting milk very difficult. As stated in Sommer's report, the stability of milk under sterilization may be corrected by the addition of citrates, but not unconditionally. The use of citrate must be limited to such an amount that alcohol-positive milk is made negative with 70 per cent alcohol, but is still positive with 75 per cent alcohol. Beyond this limit, the addition of the citrate decreases the stability. When an alcohol-negative milk was treated with citrate, the effect was similar, but with a different citrate. The heat-resisting power of the milk increased with the addition of acid citrate. The maximum stability was reached when it was made positive with 75 per cent alcohol but still negative with 70 per cent alcohol. When an alkaline citrate was added to such a milk, the heat resistance was greatly reduced. These investigators state that this effect is not specific to citrate itself, but is due rather to its buffer action and peptizing effect, since similar results can be obtained with borates. In a milk that can be stabilized in this manner, the maximum increase in stability is easily overreached, and overtreatment may reverse the effect.

They also state that the *p*H effect may completely overshadow any action of the buffer solutions studied, especially if the sample lies above or below a *p*H range of about 6.58 to 6.65. Within this range, changes in salt balance are very important; while outside its changes in *p*H produce more marked effect. They further state that the mere fact that the alcohol test is positive or negative does not prove anything as to the heat stability of milk. Turning an alcohol-positive milk negative by citrate or other buffers does not increase the stability unless the optimum combination of *p*H and salt balance is approached. This optimum is the resultant of several variables and consequently is an expression of the colloidal peculiarities of particular samples. It is different in different milks. In a majority of the samples studied, the optimum was found to lie at or near the point where the milk was positive to 75 per cent alcohol and negative to 70 per cent alcohol.

Grading Milk for Evaporated Milk.—The milk should first be tested for flavor, primarily by smell. An experienced tester can judge of the fresness of milk very accurately and quickly by placing his nose to the mouth of the can at the moment the lid is taken off. Only milk of sweet, fresh flavor must be taken. Any abnormal odor indicates either deterioration or contamination, and milk having such an odor is not suitable for the manufacture of evaporated milk. Sometimes samples are tested for chemical and physical properties, for grading, but experience shows that these tests should be regarded as supplementary to the flavor test.

Proper grading by flavor generally suffices for the selection of suitable milk for making evaporated milk; but the composition of the milk is very important for the yield of the product. Therefore, the samples should be tested for lactometer reading and butter fat, and the price of the milk should be fixed accordingly.

The alcohol test should be applied to detect heat-coagulable milk. Any milk that shows a positive reaction with alcohol should be rejected. In case, however, there is a positive indication of perfectly fresh milk, alcohol-positive milk may be taken, if this property is not very pronounced, and may be treated with sodium citrate or disodium phosphate to correct heat coagulation.

The acidity test may also be applied, not necessarily for the purpose of rejecting a high-acid milk, but to detect, in connection with other tests, (1) the adulteration of milk by watering, (2) neutralization, or (3) fermentation. The boiling test may also be applied in special cases.

Standardizing or Modifying Milk for Evaporated Milk.—Some manufacturers standardize the milk used in making evaporated milk. Since competition is very keen among evaporated milk manufacturers, they cannot afford to leave much more fat in the milk than is absolutely necessary, unless the public is willing to pay a premium for extra fat. On the other hand, they are compelled by law to make evaporated milk to meet established standards. There must be a certain percentage relation of fat to solids-not-fat. The milk is often standardized after being condensed, but it is better to standardize it before. To do this, it is very important to test accurately each batch of milk for butter

fat, to take the lactometer reading, and to calculate the percentage of solids-not-fat. On the basis of these tests and calculations, the amount of cream or skimmed milk to be added must be calculated.

It is possible to make "maternized" evaporated milk. As has been stated, some physicians suggest such a product for infant feeding, where good fresh milk is not available. The high temperature to which the milk is subjected in the course of manufacture destroys some of the accessory substances that are present in fresh milk, and modifies some of the constituents. Therefore, evaporated milk cannot be a perfect substitute for mother's milk. Nevertheless, its general composition may be so modified as to resemble that of mother's milk, and the resulting maternized evaporated milk may be made a satisfactory infant food if it be diluted, at the time of feeding, with a proper amount of water, and if the accessory food substances, such as vitamins and lime, in which it is deficient, be added to it. In making maternized evaporated milk, the fresh milk should be so modified before evaporation.

In order to modify milk most accurately, it is necessary to make a complete analysis of the fresh milk. In practice, however, it is impossible to wait for the results of analysis, as the milk deteriorates very quickly. Also, the storage of fresh milk in large quantities is an economic impossibility. Fortunately, there is a certain relation between fat and protein contents, and the contents of lactose and ash are relatively constant. The test for fat is comparatively easy and can be made in a short time. Therefore, in practice the fresh milk is tested for fat only, and is modified accordingly. Mother's milk contains about the same percentage of fat as average cow's milk, much more lactose, and less protein and ash. In maternizing cow's milk, it is first diluted to reduce the casein content to the equivalent of that of mother's milk. This reduces all other constituents as well, and makes the milk deficient in fat and lactose, especially the latter. To meet these deficiencies, fat is added in the form of cream, and lactose in the form of commercial lactose or some other sugar. In modifying the fresh milk for evaporated milk, it is not necessary to dilute it; but the milk should be so modified as to bring the constituents

to the proper proportions by the addition of fat and sugar. The proportions of the milk constituents in mother's and cow's milk, taking protein as the unit, are shown in the following table.

PROPORTION OF MILK CONSTITUENTS, TAKING PROTEIN AS UNIT

	Protein	Fat	Lactose	Ash
Human milk........	1.00	1.65	2.71	0.14
Cow's milk......	1.00	1.03	1.37	0.20
Deficiency in cow's milk	.....	0.62	1.34	

Average cow's milk contains 3.55 per cent total protein. The modified milk should contain 5.86 per cent fat and 9.62 per cent lactose. To average cow's milk, therefore, 2.22 per cent fat and 4.74 per cent sugar are to be added. Since the sugar can be very conveniently added when the evaporated milk is about to be used for infant feeding, the milk may be modified for fat only, by addition of cream before manufacture, and the directions for preparation for infant feeding may be printed on the labels of the cans.

Such milk does not take the place of mother's milk; in fact, there is no preparation that will do so. Infants should be nursed whenever possible. All preparations for infant feeding are only substitutes to be used in unavoidable cases, and great care should be taken in their manufacture.

MANUFACTURE OF EVAPORATED MILK

Heating.—The first step in the manufacture of evaporated milk is to heat the milk. The object of this is much the same as in the manufacture of the sweetened product, being different only in that no sugar is to be dissolved. The temperature to which the milk is subjected is generally higher, and the heating longer, than in the case of sweetened condensed milk. Sommer found that the more the milk is subjected to preheating, the better the evaporated milk stands the sterilization temperature.

The heating method for sweetened condensed milk may well be applied to evaporated milk. The continuous heater, however, is not suitable for evaporated milk, as it is necessary to hold a certain temperature before the milk is sucked into the vacuum

pan. It is recommended, therefore, that a series of small heaters be provided, rather than one or two large ones. The milk, as it comes from the farms, is allowed to run into heaters, one by one, and the heat is applied as soon as one is filled. The temperature is brought up almost to the boiling point and kept there for five to ten minutes. As soon as the second heater is filled, heat is applied to it, and so on to the rest of the heaters. When the milk in the first heater has been heated properly, it is sucked into the vacuum pan for evaporation. By the time all the milk in the first heater has been sucked in, the second must be ready for suction, and so on to the rest. When a heater is empty after suction, it may receive a second charge of milk, unless there are enough heaters provided to take care of all the milk received. Jacketed heaters with stirrers are best adapted to the preheating of milk for the manufacture of evaporated milk.

Preheating destroys most of the bacteria, molds, and enzymes, but does not make the milk sterile. Experiments show that milk received at factories may contain anywhere from 5 million to 15 million bacteria per cubic centimeter. This number may be reduced by heating to 100 or even less, but never to zero. It is believed that, by heating, the casein of milk is somewhat changed, and that partial precipitation occurs, though it may be invisible to the naked eye. The higher the temperature the greater is the change. It is also claimed that this partial precipitation of casein prevents the formation of a big and hard curd on sterilization of evaporated milk. There is, however, no definite experimental evidence to support this relation, except that such a correlation sometimes occurs in practice. It is true that a considerable portion, if not all, of the albumin is coagulated and that some of the calcium salts are rendered insoluble by this treatment.

The milk should be heated without delay. A considerable time elapses between milking and receiving at the factory. Even with the best care on the part of producers, the milk is very apt to change considerably during this time, especially in warm seasons of the year. It is well to recognize that in warm weather the milk received at the platform is likely to be near the turning point, unless it has already turned sour. If, for any reason, the heating is delayed, and the milk must be stored for any length

of time, it should be cooled at once with ice-cold water, or better, with brine, and kept at a low temperature until ready for heating.

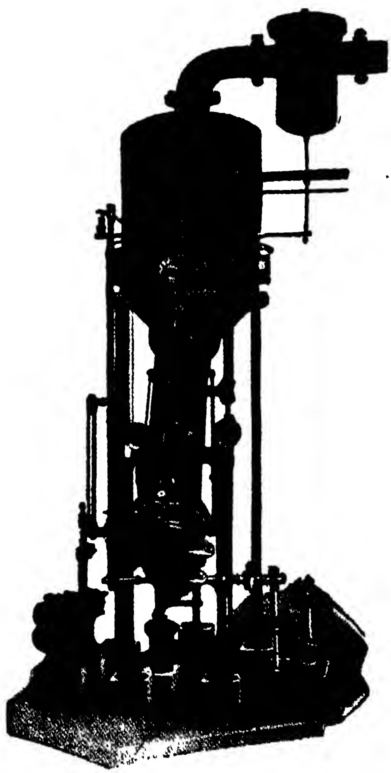
Evaporation.—The evaporation is usually done in the vacuum pan in much the same way as with sweetened condensed milk. The same vacuum pan, condenser, and pump may be used. The manner of operation is essentially the same. All the precautions observed in manipulating the vacuum pan in the manufacture of the sweetened product are also to be observed in the manufacture of evaporated milk. The operation is even more difficult, as the unsweetened milk foams more in the vacuum pan and the splashing is more vigorous. The unsweetened milk is more liable to burn on to the heating surfaces.

The steam should never be turned on to any of the heating appliances until they are completely covered with milk, leaving no exposed heating surface during boiling. It should be borne in mind that foaming and splashing are entirely different phenomena in boiling. The greatest amount of foaming occurs when the boiling is not vigorous but the temperature is high enough to evaporate the milk under a partial vacuum. Splashing is due to a partial superheating. When hot milk is first sucked in, it boils rather vigorously at the moment of entering the vacuum pan, but soon settles and begins to foam. As the foaming increases, the heating surface is soon covered with milk. In reality, however, the volume of the milk is much less than it appears to be. When the steam is turned on, a vigorous boiling soon starts, the foam is greatly reduced, and a part of the heating surface may be exposed. This is very dangerous. The exposure of the heating surface not only causes the milk to burn on, but also causes greater splashing, especially before the burning takes place.

Foaming and splashing are both very dangerous in the operation of the vacuum pan. When there is much foaming, a small quantity of milk may soon fill up the space in the pan and then be sucked out through the pump and wasted. When there is violent and high splashing, the milk droplets are thrown out of the pan and finally drawn out to the sewer, as already stated in a former chapter.

The unsweetened milk foams more because its density is lower than that of sweetened milk. The colloidal dispersion

of the casein in milk becomes very unstable on condensing and is subject to coagulation by heat, especially with milk of poor quality. As the condensation progresses, there may occur a partial coagulation on the heating surfaces of the pan, and the milk may finally stick to them. A small quantity of coagulated material sticking on the heating surfaces prevents heat conduction and retards evaporation. This again becomes a cause of foaming.



Manufactured by Buffalo Foundry and Machine Co

FIG. 41.—BUFLOVAK RAPID CIRCULATION EVAPORATOR.

In operating the vacuum pan, care must be taken in regard to the rate of suction of supply milk and the turning on of the steam into the heating appliances. The rate of milk suction should be fast at first, to insure a quick covering of the heating surfaces, provided that the vacuum in the pan does not go lower than 25 ins. After all the heating surfaces are covered and the steam is turned on to full capacity, the suction should be so regulated as to keep nearly the same level of milk in the pan. The level of the boiling milk in the pan should be a little lower than in the case of sweetened milk. As long as the steam is completely used for heating, as shown by the fact that the exhaust has no live steam mixed with it, 25 lbs. or more of steam may be applied to good advantage. High-pressure steam, however, often causes a localized high temperature at the inlet and consequent coagulation of casein. Therefore, the rate of admission of steam should be a little less than in case of sweetened milk.

The ratio of condensation of evaporated milk is about the same as that of the sweetened milk, being 2 to $2\frac{1}{2}$ parts of fresh

milk to 1 part of the finished product; but the actual evaporation is much less in the evaporated milk. In condensing sweetened milk, about 75 lbs. of water are evaporated from every 100 lbs. of fresh milk; while in the case of the evaporated milk about 60 lbs. of water are evaporated, when both are condensed at the ratio of $2\frac{1}{2}$ parts of fresh milk to 1 part of the finished product. Usually, the sweetened product is condensed a little further, and the evaporated milk a little less. This makes all the more difference in the amount of water to be evaporated. All things, therefore, tend to make the capacity of the same vacuum pan less for the manufacture of evaporated milk than for that of sweetened condensed milk.

Before the advent of the homogenizer, there was an art in keeping the fat from separating in the evaporated milk in manufacturing this product. It was done by a careful preheating and by controlling the heat in the sterilizer. The superheating of the milk in the vacuum pan was an important factor in keeping the fat from separating. This practice is still in use in some factories. When the evaporation is nearly completed, the steam is entirely shut off from the jacket and coils, the water valve leading to the condenser is closed, the vacuum pump is stopped, and then live steam is turned into the milk in the vacuum pan. The vapor pressure in the vacuum pan increases and the vacuum drops until the vacuum gauge shows about 6 to 8 ins.; the steam is then turned off. The temperature inside the vacuum pan rises to 180° to 200° F. As soon as the superheating is finished, the vacuum pump is carefully started again and the evaporation is completed in the usual way. Special care must be taken in restarting the pan operation, as so much foaming takes place that the milk is apt to be sucked out of the pan and wasted. As there is danger of loss by superheating in the vacuum pan, this is often done after the milk has been drawn out. In such a case, the milk is condensed a little further than usual and the steam is applied in an open vessel. The condensation water of the steam dilutes the product. Sometimes, water is added to bring the milk to a proper consistency.

It is said that the superheating partially precipitates the casein and encloses the fat in it, preventing the separation of fat. It is also claimed that this minimizes the danger of the formation

of too hard a curd in sterilization. It lends the body of the milk an appearance of thicker consistency and gives it a more creamy character. Whether or not the superheating is advantageous is still an open question; taking for granted that it is advantageous to the finished product, its disadvantages in the manufacturing process must also be recognized. If there were any way of avoiding the superheating, it would be an improvement. Homogenizing answers almost all the purposes of superheating. When properly done, it is better than superheating, eliminating most of the disadvantages of the latter. Therefore, it is better to avoid superheating in the manufacture of evaporated milk.

Striking.—Striking the finishing point of evaporation is much easier in the case of evaporated milk than in that of sweetened condensed milk. It can be accomplished by testing the milk for density with a hydrometer. The evaporated milk is not so viscous and syrupy as the sweetened condensed milk; it has the consistency of rich milk or thin cream. It is, therefore, rather difficult to determine when it is sufficiently condensed by merely judging its consistency with the naked eye. The density varies, first of all, with the fat content. It also varies with the degree of condensation, which is governed by the quality of the supply milk. Generally, it has a density of 1.05 to 1.075 specific gravity at 60° F.

A special hydrometer, reading the specific gravity between 1.01 and 1.10, or a Baumé hydrometer, registering 5 to 15 degrees, may be employed in determining the density. The hydrometer should be subdivided to read either 0.001 specific gravity or a tenth of a Baumé degree. The Westphal balance may also be used advantageously for more accurate work. When this balance is set beforehand, the determination can be very quickly made, and the result is very accurate, and therefore applicable to factory practice.

The sample is drawn from the vacuum pan in the same way as with sweetened condensed milk, and is received in a cylinder. The density is taken at a standard temperature of 60° F. In practice, there should not be much delay in the determination of the density, as the evaporation is going on in the vacuum pan every moment, even after the sample is drawn. Therefore, the hydrometer reading is usually taken at 120° F., which is nearer

the temperature of the milk as drawn from the vacuum pan, and the correction for the temperature is made to 60° F. The density is naturally lower at a higher temperature. The Baumé hydrometer reads about 1.88 degrees lower, and the specific gravity is approximately 0.013 lower, at 120° F. than at the standard temperature of 60° F. In striking the batch of evaporated milk, this must be taken into consideration. The sample may, therefore, be struck at a Baumé reading of 6° to 9°, or the specific gravity of 1.04 to 1.07 at 120° F., depending on the quality of supply milk and the consistency of the product.

Standardizing.—The standardization is better done before condensing. Some, however, recommend that the milk be condensed a little beyond the desired concentration and the product standardized to the desired composition, with distilled water, for dilution; skimmed milk, for bringing the fat down without material decrease in solids-not-fat; or cream, to make up the deficiency in fat.

If the finished product is to be standardized, the evaporated milk is weighed and put into a standardizing vat or tank with some device for agitation, or it may be drawn directly into a vat or tank resting on a scale; thus the amount of evaporated milk can be weighed in a batch. The degree of condensation may be calculated by dividing the weight of the original milk by the weight of the evaporated milk. It may also be calculated from the percentages of fat in the original milk and in the evaporated milk. The percentage of fat in the evaporated milk is divided by the percentage of fat in the original milk. With the former method of calculation, if the fat content of the original milk is known, the percentage of fat in the evaporated milk can be approximately calculated, and the standardization can be done accordingly. With the latter method, if the amount of the original milk is known, the weight of the evaporated milk can be approximately calculated, and the standardizing can be done accordingly. Both of these methods are practical and fairly accurate, provided that there is no loss during the process of manufacture. In reality, however, we must figure on more or less loss of milk at every step of handling, from the time the milk is received at the platform until it goes into the standardizing vat. Especially during the process of condensing, there are

many chances for loss, unless suction, heating, and vacuum are well regulated and the restarting of evaporation after the superheating process is well controlled.

The most accurate work may be done by weighing the amount of the evaporated milk accurately and testing it for fat. Pearson's method of standardizing may be conveniently applied. This method is nothing but an application of the following algebraic formula.

$$X = \frac{M(F - f)}{f' - F},$$

where X is the weight of standardizing material,
M is the weight of the evaporated milk,
F is the standard percentage of fat of the evaporated milk,
f is the observed fat percentage of the evaporated milk, and
f' is the fat percentage of the standardizing material.

If the algebraic calculation is made, the above formula can be applied to any case, i.e., either when the fat is to be added by addition of cream or when it is to be decreased by addition of milk, skimmed milk, or distilled water. Those who are not accustomed to algebraic calculations may apply the above formula for standardizing evaporated milk with cream to increase the fat content, and the next formula to lower the fat percentage of evaporated milk with milk, skimmed milk, or distilled water.

$$X = \frac{M(f - F)}{F - f'}.$$

Example I.—The weight of the evaporated milk is 4000 lbs., and its fat content is 7.5 per cent. How much cream, with a fat test of 30 per cent, is required to meet the standard of 8 per cent fat in the product?

M = 4000 lbs.
f = 7.5 per cent
f' = 30 per cent
F = 8 per cent

Then

$$X = \frac{M(F - f)}{f' - F} = \frac{4000(8 - 7.5)}{30 - 8} = 90.9 \text{ lbs.}$$

Answer: 90.9 lbs. of 30 per cent cream are to be added to bring the fat content of the evaporated milk up to the standard of 8 per cent.

Example II.—The weight of the evaporated milk is 3500 lbs. and its fat content is 8.5 per cent. How much milk, with a fat test of 3.5 per cent, is to be added to bring the fat percentage of the evaporated milk down to the standard of 8 per cent?

$$\begin{aligned} M &= 3500 \text{ lbs.} \\ f &= 8.5 \text{ per cent} \\ f' &= 3.5 \text{ per cent} \\ F &= 8 \text{ per cent} \end{aligned}$$

Then

$$X = \frac{M(f - F)}{F - f'} = \frac{3500(8.5 - 8)}{8 - 3.5} = 388.8 \text{ lbs.}$$

Answer: 388.8 lbs. of 3.5 per cent milk are to be added to bring the fat content of the evaporated milk down to the standard of 8 per cent.

Example III.—The weight of the evaporated milk is 3200 lbs. and its fat test is 8.8 per cent. How much skimmed milk or distilled water is to be added to standardize it to 8.0 per cent? Strictly speaking, the fat content of the skimmed milk is to be taken into consideration; but, since properly machined skimmed milk should not contain more than 0.05 per cent fat, it may be neglected in practical calculations.

$$\begin{aligned} M &= 3200 \text{ lbs.} \\ f &= 8.8 \text{ per cent} \\ f' &= 0 \text{ per cent} \\ F &= 8 \text{ per cent} \end{aligned}$$

Then

$$X = \frac{M(f - F)}{F - f'} = \frac{3200(8.8 - 8)}{8} = 320 \text{ lbs.}$$

Answer: 320 lbs. of skimmed milk or distilled water are to be added to bring the fat content of the evaporated milk to the standard of 8 per cent.

After the amount of standardizing material to be added has been calculated, it is carefully weighed and added to the batch of evaporated milk. The mixture must be thoroughly stirred to

insure uniformity. To prove the accuracy of the standardizing and the thoroughness of the mixing, samples from different parts of the vat or tank are taken and tested for fat, and preferably also for solids.

Homogenizing.—As has been stated, one of the important defects in canned evaporated milk is the separation of fat on keeping. The prevention of this defect is the most difficult part of the manufacture of evaporated milk. Preheating, superheating, and high sterilizing heat all help more or less to keep the fat from separating, but they are not the safest and surest ways of preventing it from doing so; they greatly increase the viscosity of the evaporated milk through the partial coagulation of casein. Some claim that live steam, blown into milk, homogenizes the fat globules, and hence prevents fat separation. There is, however, no experimental evidence to prove this assumption. On the contrary, microscopic examination of heated milk does not show any change in the size of the fat globules. The homogenization of the fat globules can only be accomplished by the use of a homogenizer.

There are contradictory theories in regard to the action of homogenizers. It was first thought that the fat globules were split into finer globules by being forced through microscopical orifices. This was denied by later investigators, who pointed out that the orifices of the homogenizer, through which the fat globules are to pass, are much larger than the globules themselves. It has been suggested that homogenization of the fat globules does not take place while the milk is passing through the orifices, but occurs upon release of the high pressure to which the milk is subjected. How and why the homogenization takes place upon the release of the high pressure is not explained. Hunziker suggests that the homogenizing action is very similar in its atomizing cause and effect to that which takes place in the spraying process in drying milk. Since the fat globules of the homogenized milk are smaller than those of the sprayed powdered milk, the homogenizer must be much more efficient than the spraying in homogenizing the fat globules. Hunziker attributes this to the smaller sizes of the openings through which the milk must pass in the homogenizer. There is, however, no proof of these assumptions. When milk is forced through very small orifices and released to

greater openings, it is atomized and spraying takes place. This atomizing effect is greater with a greater pressure. The homogenizing effect must therefore be greater with higher pressure, and this is true to a certain extent. But the pressure applied in the spray-drying process is more than twice as great as that applied to the homogenizer, and yet the homogenizing effect of the spraying is much slighter. As will be explained in the chapter on milk powder, the author's experience shows that the homogenizing effect of spray drying under the same pressures depends on the concentration of the milk. In fact, with spray drying,

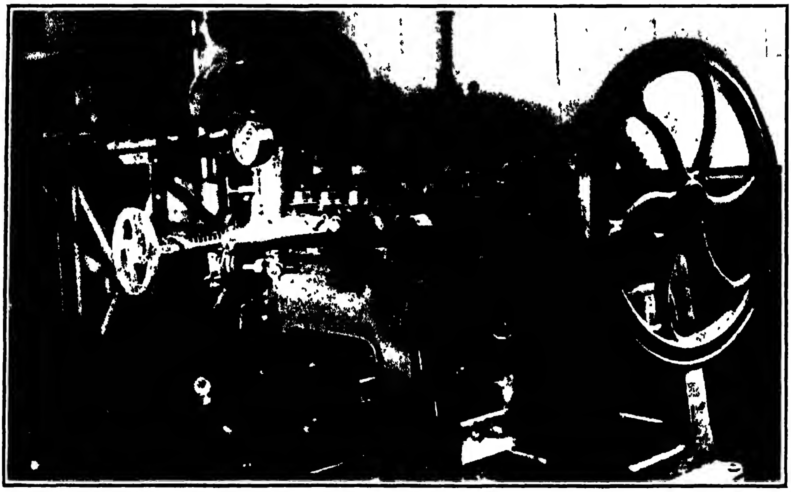


FIG. 42.—HOMOGENIZER.

practically no homogenizing effect was observed when whole milk was sprayed directly instead of being condensed beforehand. Even clusters of the fat globules were observed in this case. With homogenizers, the milk can be successfully homogenized without condensing. These facts show that the atomizing of the milk under a high pressure cannot be the sole cause of homogenizing.

At any rate, in homogenizing, the evaporated milk is passed through a homogenizer before it cools down. A lower temperature and a higher pressure make the milk more viscous. This increase in viscosity is due partly to the reduction of fat globules to smaller sizes, but more to the partial precipitation of casein,

which sometimes produces a copious precipitate when the milk is sterilized, making the evaporated milk curdy. Therefore, no more pressure than is absolutely necessary for satisfactory homogenizing should be applied to the homogenizer. It is suggested that a pressure of 1000 to 1500 lbs. per square inch is most satisfactory for homogenizing evaporated milk. Too low a temperature causes the fat globules to form clusters rather than to split up into finer globules. A temperature of 120° to 140° F. is most satisfactory. It is best to run the machine at uniform pressure and temperature to insure a uniform product. Before the pressure is regulated, the evaporated milk is not uniformly homogenized. Therefore, the first milk coming out of the machine should be returned to the supply tank.

Cooling.—The evaporated milk should be cooled down soon after it is drawn out of the vacuum pan. It is not at all sterile, nor are any preserving materials added to it. Therefore, if it remains warm too long, the bacteria begin to multiply and spoil the product. If standardizing or homogenizing is not required, the evaporated milk should be led at once to the cooler. No time should be lost in standardizing and homogenizing when they are practiced.

The cooling of evaporated milk is simple when compared with the cooling of sweetened condensed milk. No attention need be given to the crystallization of milk sugar. The only crystals that may form in the evaporated milk are crystals of tricalcium citrate, which appear on the bottom of the cans after the evaporated milk has been aged for a considerable time. The crystals are white, gritty particles, but the quantity is so small that they do not affect the quality of the product materially. The factors influencing the appearance of the crystals are, first, variations in the quantities of calcium and citric acid present in the original milk; second, the degree of condensation, and third, the storage temperature. Since the crystals appear after the product has been a long time in storage, the method of cooling has nothing to do with their appearance, shape, size, etc.

The cooling of the evaporated milk may be accomplished by a method similar to that used for fresh milk or cream. The coolers used for sweetened condensed milk are sometimes used for the evaporated product. There is no particular system which is con-

sidered the best for cooling evaporated milk. Any type of cooler or any system that cools the evaporated milk down to any desired temperature as quickly as possible is suitable for the purpose. A surface cooler, with or without a cover, may advantageously be used. The evaporated milk from the homogenizer is run over a surface cooler. Where a supply of very cold water is plentiful, the cooling may be done solely with water. Otherwise, the cooler is best made in two sections, and the cooling may be done with cold water at the upper section and with brine at the lower section. With this system, the evaporated milk can be cooled to a very low temperature. Sometimes it is cooled down to about 50° F. with water, and then further cooled with brine in a holding tank. If the evaporated milk is to be kept over night before canning and sterilizing, this method of cooling is the best.

A double pipe cooler is also used. The evaporated milk is forced through the inner tube, and cold water or brine passes between the inner and outer tubes. With this system, danger of bacterial contamination from the air is eliminated, and, if care is taken in washing and sterilizing, it is very sanitary. On the other hand, if there is any neglect in washing and sterilizing the inner tube after use, it becomes a seat of bacterial contamination and is much worse than a surface cooler. If the cooler is properly operated, the cooling is very efficient, but careless operation is disastrous. The success of the cooling depends on the man behind the cooler, just as in all other operations performed by machinery.

If the evaporated milk is to be held for any length of time, the cooled milk must be led to a holding tank or vat. A glass-lined holding tank with propellers and jacket is preferable to a vat. The capacity of the holding tank should be such that it holds a day's run. Thus the day's output is made uniform. A vat cooler or pasteurizer may be substituted for the holding tank. The movable coils act as a stirrer. Sometimes the standardization of the evaporated milk is deferred until all the batches of the day's run have reached the holding tank. This method is advantageous, for it saves much time and labor which would otherwise be spent in testing, calculating, and standardizing individual batches, especially when more than two batches of a day's run are to be held over night. It is disadvantageous, however, in case fat is to be

added in the form of cream, because the added fat is very likely to separate out if it is not homogenized.

It is best to complete a day's work without holding the evaporated milk over night. This can be done only when a day's run is very small, and the condensing can be finished in the forenoon. Otherwise, the evaporated milk must be held in a holding tank or vat provided with equipment for cooling and stirring. For a successful work, it must be cooled to 40° to 45° F. and held at that temperature until the filling into cans commences. The stirring is necessary to insure uniform cooling.

In case the scale of the factory is very small and there is no holding tank or vat, the cooled evaporated milk may be put into ordinary milk cans and placed in a cooling tank with cold running water or with ice water. If there is a cold-storage room, the cans may be taken into it and held there.

The temperature to which the evaporated milk is to be cooled and held is such that bacterial growth is practically prevented. The lower the temperature, the less multiplication of bacteria occurs. A temperature lower than 40° F. is not necessary, however, since the evaporated milk should not be held any longer than one day.

Canning.—Where a day's run can be canned on the day of manufacture, the cans may be filled at once after the milk is cooled, or even before it is cooled, provided the cans can be sterilized immediately after they are filled. Generally, the cooled and held evaporated milk is filled into tin cans on the day following manufacture. Tin cans range in capacity from 8 oz. to a gallon, the most popular size being 16 oz.

The filling is usually done automatically with a machine. There are different types of cans, and machines designed especially to fill them. The most modern and popular type of tin can for evaporated milk is the " venthole " type. These cans are unlike the ordinary ones in that the opening for filling is very small, no larger than $\frac{1}{8}$ in. in diameter. Cans of this type cannot be filled by hand, but are filled with a special filling machine. This automatic filling machine is provided with automatic tippers, and the filled cans come out of the machine already sealed and ready for sterilization. The sealing is very efficient, economical, and sanitary. In operating this machine, the temperature of the evap-

orated milk should be very carefully regulated. A temperature between 40° and 50° F. seems to be most satisfactory. It is said that a temperature higher than 60° F. often causes serious annoyance by making the milk foam while the cans are being filled.

Besides the venthole cans, the sanitary cans and other large-hole cans are used for evaporated milk. In fact, before the invention of the venthole cans, they were universally used. At present, however, they have been almost entirely replaced by the venthole cans. Where hand filling is still practiced, the old-style cans are the only ones that can be used. Many styles and types of filling machines are available for the automatic filling of these cans. The temperature of the evaporated milk is not so important in filling large-hole cans, but a lower temperature is better. Hot evaporated milk is sometimes poured in to these cans immediately after condensing, when it is not standardized or homogenized. The cans are capped and sealed immediately after filling. The sealing must be hermetical and strong enough to withstand the strain of the subsequent sterilizing process.

Before the filled cans are placed in a sterilizer, they must be tested to detect leakers. This is very important, because a can is a total loss if it is put into the sterilizers in a leaking condition. Leakers can be saved if they are picked out by testing, and the leaks mended before the cans are subjected to the sterilizing process. The testing is done by placing the filled cans in a hot-water bath. The leakers will give out bubbles in the hot water. This test is a safeguard against loss by leakage in the sterilizing process, but is not a guarantee of non-leakage. A slight weakness in sealing cannot be detected by the hot-water test but causes the can to leak in the sterilizer. Therefore, a thorough and strong sealing is the only guarantee of non-leakage.

The cans, having been filled and tested, are now ready for sterilizing. In case, however, immediate sterilizing is impossible and the cans must be held for some length of time, they should be placed in ice water or in a refrigerator to avoid spoilage. This precaution is especially important during the summer season.

Sterilizing.—Unlike sweetened condensed milk, evaporated milk is made to keep by sterilization, and its keeping quality depends entirely upon the thoroughness with which this operation is performed. Not only the keeping quality but also the physical

and chemical properties are greatly affected by the process of sterilization. Therefore, the proper sterilization of the evaporated milk is one of the most important operations in its manufacture.

The thermal death point of microörganisms varies considerably according to species. With many species of bacteria, it lies as low as between 52° and 58° C. (126° and 136° F.) On the other hand, some species flourish at 70° C. (158° F.). Tubercle bacilli, for instance, may die at as low a temperature as 55° C. (131° F.), when kept at this temperature for four hours. An instantaneous heating at a higher temperature, e.g., 85° C. (185° F.), will kill these bacilli. Therefore, the ordinary bacteria can be destroyed at a rather low temperature; in fact, more than 99 per cent of bacteria are killed by subjecting the milk to a pasteurizing temperature of 60° C. (140° F.) for thirty minutes, or to a temperature of 80° C. (176° F.) momentarily. It is impossible, however, to make milk absolutely sterile at these temperatures. The thermophilic bacteria, which have been found in the intestinal tract, in excreta, and in sewage, grow best at temperatures lower than 60° C. (140° F.) It is well known, however, that many of the non-thermophilic spore-bearing bacteria, occurring more or less frequently in milk, can withstand a temperature of 80° C. (176° F.) for as long as fifteen minutes. Klein's *Bacillus enteritidis sporogenes* is an instance of this type. Resistance to high heat on the part of this type of bacteria is due to the spores they bear. The capsule of the spore is thicker and stronger, and its protoplasm is more concentrated, than that of the parent bacillus. Cohn has suggested that the capsule of a spore is in reality a double envelope, an inner one of fatty and an outer of gelatinous nature, and that this accounts for the resistance of the spore to heat and desiccation. The standard of the sterilization should always be set at the highest power of resistance of either bacillus or spore.

The degree of resistance differs greatly with different spores. Yeast spores, for instance, are rather weak, while bacterial spores are usually very resistant. Different species of bacteria show different degrees of resistance to heat. Some of the spores from soil bacteria show extremely high resistance. The spores of *B. semicolstridium* can stand boiling (100° C.) for ten hours. The spores of *B. cylindricus* and *B. tostus* are killed only after twenty hours' heating in water at 100° C. Therefore, there are some

spores that cannot be killed simply by boiling. A long period of boiling may kill them, but such treatment is not practical in sterilizing milk on a commercial scale. Heating above the boiling-point, which can be accomplished by heating the milk under pressure, is essential in securing thorough sterilization. The spores of the hay bacillus, a common organism found in milk, are very resistant to heat; they can stand heating above 100° C. for a short time. The action of heat in killing spores has a time factor. The thermal death points of the hay bacillus and of *B. Robur* with their time factors, are as follows:

THE RELATION OF TEMPERATURE AND THE TIME OF HEATING TO THE DEATH OF SPORES

Temperature, C.	The Time of Heating to Kill Spores, Hay Bacillus	*B. Robur*
110°	36 min.	5 2 min.
120°	7 2 min.	81 sec.
130°	89 sec.	12 sec.
140°	22 sec.	

The spores of *B. robur* can be killed by heating in hot water under pressure at 130° C. for twelve seconds; while those of the hay bacillus must be held eighty-nine seconds, nearly eight times as long, at the same temperature, before they are killed. In sterilizing, all of these high heat-resisting spores must be killed. If the bacterial flora can be determined before sterilizing, the temperature to which the evaporated milk is to be subjected can be controlled very easily and unnecessary heating may be avoided. In practice, however, it is impossible to do this. Therefore, the temperature must be high enough to insure the death of all spores.

Sterilizers.—There are on the market various makes of sterilizers which can be successfully used for evaporated milk when they are properly operated. The most satisfactory sterilizers are made in the shape of a huge boiler-like cylinder, the inside of which is equipped with a revolving framework, a perforated steam-distributing pipe in the bottom extending over the entire length of the sterilizer, a water-distributing pipe in the top of the sterilizer running parallel with the steam pipe, and a water exhaust. In some sterilizers, the framework does not revolve but moves back and forth by means of a direct-acting, steam-

driven piston. On the outside of the sterilizer, a gauge registering both pressure and vacuum (or separate gauges for steam pressure and vacuum), a water gauge, a blow-off valve, and a high-temperature thermometer are attached. A self-registering thermometer is very useful.

The sizes of sterilizers are varied to suit all ranges of production. A small pilot sterilizer, which sterilizes a few cans at a

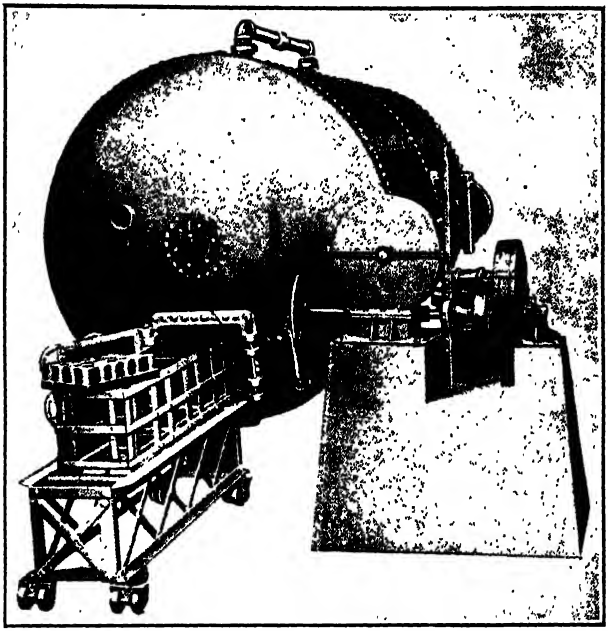


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FIG. 43.—STERILIZER FOR EVAPORATED MILK.

time, is very useful in determining the proper heat and time to be applied to the evaporated milk in order to produce the desired consistency and color without spoiling the product.

Operation of Sterilizer.—Sealed cans are loaded into heavy iron trays which accompany the sterilizer, and placed and locked into the framework of the latter. The sterilizer is closed tightly after being loaded, and the framework is put in motion. The steam is now turned on. The application of heat, by means of steam, should be uniform throughout the pile of tin cans.

Heating with direct steam has many disadvantages. With

this method a uniform heating cannot be insured. While it is a quicker way of heating, it is too abrupt, is liable to superheat the tin cans, and may cause a granular coagulation, especially when the milk is poor in quality. Between layers of tin cans, air pockets are often formed. The steam does not enter these pockets, and uneven heating results. To avoid these disadvantages, the sterilizer may be filled one-third full of water, so that all the cans pass through the water during the operation. The water distributes the heat uniformly and eliminates the air pockets in the system. In this case, the steam is directed into the water.

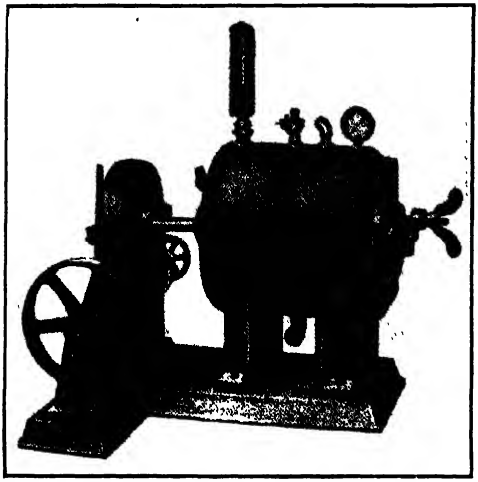

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FIG. 44.—EXPERIMENTAL OR PILOT STERILIZER.

When the steam is first applied, the blow-off valve is left open until nearly all the air in the sterilizer is driven off and the inside is full of steam, as shown by the temperature inside the sterilizer. When the temperature rises to 212° F., the blow-off valve is closed. The time required for this depends on the capacity of the sterilizer and the amount of water in it. The manner and rate of applying the steam also control the time. Usually, ten to fifteen minutes are required. The heating is continued after this, but the temperature to which the sterilizer is raised and the rate and period of heating depend on the condition of the evaporated milk. The concentration is one of the most important factors in determining the degree of heating. The more concentrated the evaporated milk is, the less heat it stands. The characteristics of the milk form another important factor. All milk does not stand heating equally well under the same conditions. The locality and the season of the year influence the properties of the milk, and hence its resistance to heating. The heat-resisting property of the evaporated product is best determined by testing a few

sample cans in a pilot sterilizer, as mentioned before. As long as the evaporated milk can stand heating, the temperature should be high enough, and the duration of exposure to heating long enough, to insure absolute sterility. It is said that a minimum of fifteen minutes, and a maximum of twenty minutes, should be taken to raise the temperature in the sterilizer from room temperature to the sterilizing temperature. When water is used, the heating may be accomplished in a shorter time, while a longer time should be allowed to insure a uniform heating with direct steam. It is recommended that, in the last ten minutes of the so-called "coming-up time," the temperature be raised at a rate of 5 degrees per minute.

The temperature to which the sterilizer is raised depends on the holding time. Some manufacturers use a high temperature and hold it for a short time, while others employ a lower temperature and hold it longer. The minimum temperature required is 240° F., which should be held for at least fifteen minutes. Where the quality of milk is poor and it cannot stand such a high temperature, it is recommended to heat to about 230° F. In such a case, the last 10° rise in temperature should occupy from thirty-five to forty-five minutes. The maximum temperature is 240° F., with a holding time of fifteen minutes.

In practice, the sterilizer reel is usually operated constantly during the sterilizing and cooling processes. In some cases, however, it is the custom to stop the reel either at intervals or when the maximum temperature is reached. In such cases the temperature is raised rapidly and the reel is stopped for fifteen to twenty minutes. After this, the cooling process begins and the reel is again put into motion. The speed of the reel has a great influence on the quality of the product. The faster the reel is operated, the more rapidly the milk will be heated during the sterilizing process and cooled at the end of the run. Too high a speed, on the other hand, causes a clabbery product. The proper speed of the reel, which differs somewhat for different makes of machines, is from 6 to 10 revolutions per minute. A higher-capacity sterilizer should be turned more slowly than a lower-capacity machine, as a larger sterilizer usually has a greater diameter, which causes a longer travel of cans in one turn.

Cooling Process.—When the proper temperature has been

reached and held for the proper time, the cooling operation should be started. The steam is shut off, and the valves of the exhaust and drain should be opened. The cold water is turned in and sprayed when the temperature of the sterilizer has dropped to about 220° F., the reel being in motion. In fifteen to twenty minutes the temperature inside the cans of milk should have been reduced to 70° to 80° F. The rate of cooling depends on the temperature and amount of the water supplied. The water sprayed should be distributed evenly throughout the sterilizer, so that the cooling is uniform. Rapid cooling is very important. Delay in cooling often causes the cans to bulge badly, owing to the difference between the interior and exterior pressures of the cans. It is sometimes recommended that compressed air be forced into the sterilizer to avoid any excessive bulging of the cans.

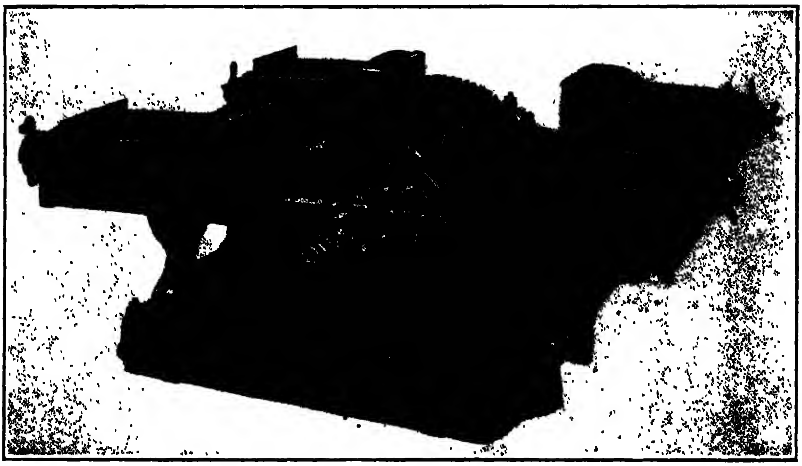
Shaking.—The high temperature to which the evaporated milk is subjected causes the casein in the milk to coagulate. Normal milk stands a high heat—about 270° F.—but its heat resistance is much reduced upon concentration. The sterilizing temperature is high enough to cause some milk to curdle in a soft curd. Such a product is unmarketable. Therefore, the sterilized milk is usually shaken in some kind of a shaking machine, by which the curd is mechanically broken to a smooth, creamy consistency.

Mojonnier [9] states that the purpose of the shaking operation is to reduce the viscosity to the desired point, with the aim of making the entire output of the plant of uniform viscosity and of a homogeneous appearance. Why the viscosity is destroyed by the shaking operation has not been explained; but the high heat partially coagulates the casein, thereby increasing the viscosity, while the shaking breaks up the coagulum, reducing the viscosity. Excessive shaking invites a disastrous result, as it causes the evaporated milk to lose its proper consistency, sometimes forming a granular curd. When visible curdy grains have been formed, nothing can remedy this defect. Shaking will not break up such a curd, but will rather encourage further granular coagulation, and the product will finally separate out to curd and whey, entirely losing its commercial value. The apparent high viscosity of the product after sterilization is the result of generalized soft

[9] The Technical Control of Dairy Products, p. 757.

curdling of the milk. The shaking may be said to have the effect of firming the coagulum by breaking the curd, much as, in making cheese, the curd of milk is broken with curd knives or some other kind of curd breakers. The curdled milk is not necessarily viscous, but it is in a semi-solid state. By breaking up the semi-solid mass, the curd is separated from the milk serum and becomes a fluid with a suspended curd. The sterilized evaporated milk is in much the same state. It is milk thickened by a partial solidification of casein, and is not really viscous.

The temperature of the evaporated milk has a great influence on the result of shaking. The breaking of the curd occurs much



Manufactured by the Fort Wayne Dairy Equipment Co.

FIG. 45.—CONDENSED MILK SHAKER.

more readily at a higher temperature; hence, at high temperatures, much less shaking is required and over-shaking is likely to result. Too low a temperature, on the other hand, often results in deficient shaking. Experience shows that ordinary room temperature is the most convenient and satisfactory for shaking. This operation should be continued for a length of time depending on the condition of the sterilized evaporated milk, the temperature, and the manner of shaking. Usually, fifteen seconds to two minutes are required.

There are two distinct types of shakers. The most common type is the batch shaking machine. One or more heavy iron boxes

or black-iron pipe crates are attached to an eccentric. The trays, filled with evaporated milk cans, are firmly mounted in these boxes or crates, and the cans are shaken back and forth violently upon operation of the machine. The other type of shaker is continuous. The evaporated milk cans are fed in at one end and run automatically into the machine. The cans are shaken as they pass through the machine, and come out at the other end. The continuous shaker is very convenient, but the control of the shaking is much more easily accomplished with the batch-type machine.

The speed of the shakers is high. The eccentric revolves three to four hundred times per minute. Such a speed on an eccentric with a high load puts a great strain on the machine. Therefore, the shaker must be made very substantial and built on a very sound foundation, otherwise it will be wrecked and the foundation smashed.

Good judgment is always necessary. It is very important in shaking the sterilized evaporated milk. The degree of shaking needed may best be judged with a few sample cans by a trial shaking. Shaking is not always an absolute necessity. If the evaporated milk has not been coagulated in the sterilizing process to such an extent as to lose its fluidity, and if the product does not form hard lumps on storing, shaking is unnecessary. It should be avoided if possible. Good quality and proper handling of the supply milk throughout the course of the manufacturing processes, together with good judgment in sterilizing, may lead to this goal.

Excess shaking often renders the evaporated milk too fluid. When this occurs, the consistency may be restored, to a certain degree, by careful reheating. This is, however, a rather dangerous practice, as it may cause a lumpy coagulation, which cannot be remedied and renders the product a total loss.

For controlling the viscosity of the evaporated milk, sodium bicarbonate is sometimes added to the batch before canning and sterilizing. Before the addition of sodium bicarbonate, the amount to be added must be determined with a sample of the evaporated milk. For this determination, the sodium bicarbonate must be actually added to the sample, which must be canned, sealed, and sterilized, and the resulting viscosity determined. Such a control is a good help in the successful manufacture of evaporated milk

of uniform quality. On the other hand, the addition of any chemical alters the natural composition of the milk, and is not very desirable for pure milk products. The aim in the manufacture of any dairy product should be to alter the natural composition and properties of the milk as little as possible. From this standpoint, the addition of sodium bicarbonate should be avoided, if possible, in the manufacture of evaporated milk. However, the use of such a chemical, while not advisable in principle, is sometimes necessary and may be a benefit to the product. In such cases it should be added, as its proper use does not harm the product nor alter its food value.

The apparent viscosity of evaporated milk after shaking cannot be preserved indefinitely. It changes in storage, the amount of change depending on the temperature and duration. A higher storage temperature reduces the viscosity much more than a lower one. It must be expected that the viscosity of evaporated milk will be greatly reduced on aging. Incubating the sterilized evaporated milk, to insure sterility before shipment, is a good practice from the standpoint of keeping up the reputation of the product. However, it must be expected that incubation will alter the consistency of the evaporated milk, making it thinner. Therefore, if incubation is practiced, a subsequent loss of consistency must be taken into account in determining the proper consistency at the close of the shaking operation.

Incubation.—If properly sterilized, evaporated milk should keep almost indefinitely without bacterial or enzymic deterioration. Whether or not every can has been perfectly sterilized cannot be determined unless the cans are allowed to stand for some days. In practice, the sterilized and shaken cans are taken into a room with a temperature of 70° to 90° F., and left there for ten to thirty days. Any defective cans are detected and sorted out. Only the sound cans are labeled, boxed, and shipped or placed in cold storage until shipped.

PLAIN CONDENSED BULK MILK, OR CONCENTRATED MILK

Plain condensed bulk milk, or concentrated milk, is an unsweetened condensed milk, made from whole, half-skimmed, or skimmed milk, which is condensed, *in vacuo* or otherwise, to one-third to

one-fourth of its original volume. This product is usually marketed in bulk in 10-gallon cans, principally to ice cream makers. It is also sold to bakers and confectioners. In rare cases, it is bottled in limited quantities and delivered to direct consumers with market milk.

This product is manufactured in almost the same way as evaporated milk. The preheating and condensing operations are alike in both cases, except that in the manufacture of plain condensed bulk milk the temperature of preheating is not necessarily so high, being 150° to 160° F. Too high a preheating temperature gives a poor consistency to the finished product. All the precautions to be observed in the manufacture of evaporated milk are also necessary in this case. The superheating is usually practiced at the latter stage of the evaporating process, to give the product a proper " liver," as it is called by the manufacturers.

Concentration is carried a little further with plain condensed bulk milk than with evaporated milk. Therefore, the striking is done at about 10° B., at 120° F., for a whole-milk product, and 14° B. for the skimmed-milk product. When a proper density is reached, the operation of the vacuum pan is stopped and the vacuum released. The product is drawn out of the pan and cooled at once. The coolers for the sweetened condensed milk are used for cooling this product as well. Recently, however, cooling vats with revolving coils or disks have also been used. The plain condensed bulk milk is not sterilized, and its keeping quality depends only on the cooling. Therefore, the cooling should be done promptly, at as low a temperature as possible. Plain condensed bulk milk is usually cooled almost to the freezing temperature. Brine is necessary as a cooling medium.

The cooled product is at once put into cans and shipped to the market. If for any reason it must be held at the factory, it must be kept in cold storage. As it is not sterile, plain condensed bulk milk should be manufactured to order. No stock is allowable.

J. H. Campbell of New York patented what is called the Campbell Process. By means of a jet of hot air blown into it, milk is concentrated to the same degree as the plain condensed bulk milk. The product is called concentrated milk. The consistency and use of concentrated milk are the same as in the

case of plain condensed bulk milk, and the two need not be considered separately. Plain condensed bulk milk and concentrated milk are simply similar products manufactured by different systems.

The Campbell Process has no advantage over the usual vacuum-pan or open-pan systems of concentrating milk. The original cost of constructing the machinery may probably be a little less, but the quality of the product is inferior. The oxygen-laden hot air causes chemical changes in the milk constituents and spoils the flavor. Whole milk, therefore, cannot be concentrated very successfully by this process, as it may become rancid. A whole-milk product is made by the Campbell process, by separating the whole milk, condensing the skimmed milk, and afterward adding the cream.

Condensed Buttermilk

The utilization of buttermilk is a great problem in creamery management. Where the scale of butter making is very small, the problem is simple, and the buttermilk is a source of income; but with large creameries in large cities, it is sometimes a nuisance. Buttermilk has, of course, a food value at least equivalent to that of skimmed milk. It has many uses if it is placed in a proper market. The trouble with buttermilk at a large creamery, located in a large city where there are no hog or poultry farms within easy reach, is the difficulty of disposing of it economically. The quantity of buttermilk produced is too great to be disposed of as fluid buttermilk for family consumption. It contains too much water to be shipped to the country for hog or poultry feed as the price obtained for it would not pay the hauling and freight expenses. If a great part of the water were eliminated and the food value more highly concentrated, it could be marketed advantageously. With this end in view, buttermilk cheese and curd are manufactured and sold as a human food and as a chicken feed. In this way, the protein of the buttermilk is in great part saved, but the rest of the nutrients, which are considerable, are still lost. The best way of saving all the nutrients of buttermilk is either to condense it or to dry it.

The difficulty in condensing buttermilk is that it usually con-

tains considerable lactic acid. When the buttermilk is heated, the casein coagulates and sticks to the heating surfaces of the condensing apparatus. To avoid this, the acid is sometimes neutralized with soda, bicarbonate of soda, lime water, ammonia, or ammonium carbonate. But one of the constituents of buttermilk that gives it a special value as food is its lactic acid, and when it is neutralized this food value is destroyed. Again, the keeping quality of the condensed buttermilk depends on the concentrated acid in it; and this important quality is also destroyed by neutralizing. Therefore, it is best to condense the buttermilk without neutralizing. Since the World War, there has been a great increase in the production of sweet cream butter, and this method of butter making is likely to continue in use. The condensing of sweet buttermilk is simple, but considerable thought must be given to its keeping quality, unless the product has a quick market.

The ordinary vacuum pan used for sweetened condensed milk is not well adapted to condensing sour buttermilk. A hot-air system of condensing, such as the Campbell process, is best adapted for this purpose. The continuous concentrator can also be used. Apparatus for the manufacture of condensed buttermilk should not have any exposed copper surface, as copper poisoning may result. All metals are more or less soluble in the acid of buttermilk. Therefore, glass-lined apparatus is best for the manufacture of condensed buttermilk; it is the most durable and safest for the product.

When the vacuum pan is used for the manufacture of condensed buttermilk, the type of vacuum pan, invented by the author, and described in an earlier chapter, should be selected, since its heating appliance is a revolving one. This pan eliminates, to a great extent, the sticking of the coagulated casein to the heating surfaces. With this pan, it is not necessary to neutralize the buttermilk. The sour buttermilk is heated in a preheater just to the boiling temperature under valcuum—120° F. or even lower. Too high a temperature causes a gummy coagulation, which is very troublesome and spoils the product. The vacuum pan should be operated at the highest possible vacuum and the lowest possible temperature, in order to avoid the sticky coagulation of casein. If the vacuum pan and other appliances

are acid-proof, more acid may be developed, or extra acid may even be added in sufficient quantity to dissolve the casein. When this is done the condensing becomes much simpler.

With a hot-air system (Campbell process) the buttermilk is heated to about 100° F. It is then led to an evaporating tank, equipped with coil and jacket, into which water of 100° to 125° F. is pumped. The hot air is then blown into the milk and serves to regulate the temperature of the milk in the evaporating tank, keeping it at about 120° F. during the greater part of the evaporation and at 90° to 100° F. toward the end. For blowing the hot air into the milk, the apparatus must be so arranged that the milk circulates around the heating surfaces of coils and jacket. The evaporation is not finished in the first tank. When the milk has been evaporated to one-half its volume it is taken to the second or auxiliary tank where the evaporation is completed.

With a continuous concentrator, the buttermilk is first heated to about 100° F. and fed in at one end. As it passes through the evaporator, it is condensed to the desired density and passes out on the other end. Since the buttermilk is in continuous motion from one end of the evaporator to the other, there is but little chance for the casein to stick to the heating surface; besides, the casein is exposed to the heat but a short time. Once the flow of the buttermilk is properly regulated, the evaporator is comparatively simple to operate.

The condensed buttermilk should be packed in acid-proof vessels. Wooden kegs are usually selected for this purpose. The sour condensed buttermilk has good keeping quality; but if the acid is neutralized or in any way removed, the product does not keep long. Therefore, it should be kept in cold storage. Condensed buttermilk is used principally as a chicken feed, but is also utilized as human food. When made properly, it is very wholesome and nutritious.

Condensed Whey, Myseost, or Primost

The by-product of the cheese factory, the whey, is condensed in the Scandinavian countries and marketed under the name of myseost or primost. The whey is filtered and put into an open pan, where it is heated directly by a fire underneath. In this way

the albumin of the whey is coagulated and made to float on the top of the whey in masses. This is dipped out, and the serum is condensed with constant stirring to about one-fourth of the original volume. The masses of albumin are then placed back in the evaporating pan and stirred very vigorously to break them into the finest possible particles. When the whole mass becomes of the consistency of curdled milk, it is quickly poured out into a wooden vessel and stirred with a wooden paddle to prevent the appearance of large crystals upon cooling. After crystallization, it is molded to a certain shape and marketed. The ordinary vacuum pan may also be used for evaporating the whey. The demand for this product is very limited.

CHAPTER V

POWDERED MILK

Cow's Milk, whole or with part of all of the cream removed, and evaporated to dryness, is variously named dry milk, desiccated milk, dehydrated milk, pulverized milk, milk powder, powdered milk, or milk flour. Sometimes it contains sucrose, and sometimes alkali or a buffer salt is added to render the product easily soluble. Some factories make a similar product from cream; this is known as cream powder.

The same considerations that brought about the manufacture of condensed milk led to study and experiment in regard to milk powder, as long ago as the middle of the past century. Many difficulties were encountered, and these have only recently been so far overcome as to permit placing powdered milk on the market in quantity.

When emulsions or suspensions of colloidal substances are dehydrated, it is often difficult, if not impossible, to effect their redispersion. This is true of casein, the principal colloidal substance in milk. Drying is apt to prevent its redispersion, or at least to make the formation of a new emulsion a very tedious process. Powdered milk should be simply fresh milk minus water, and when the water is restored the product should be indistinguishable from the original milk. That is, the physical and chemical properties, as well as the nutritive value, should be unchanged, and nothing should be present that was not contained in the original milk. In practice, the drying of milk often so changes its physical and chemical properties that it is no longer milk when the water is restored. The solubility of such colloids as calcium caseinate and lactalbumin is likely to be greatly reduced. Calcium phosphate, $CaH_2(PO_4)_2$, is also rendered insoluble. The high temperature and the drying affect the properties of these substances, making them incapable of redispersion when water is added to the powdered milk.

Exposure to the air gives opportunity for the oxidation of fat and other milk solids, causing a tallowy, rancid, or stale flavor. If the powder becomes moist, it may deteriorate because of bacterial growth and enzyme action. Successful drying of milk, therefore, demands, first, that the colloidal properties of casein and other milk solids be preserved, and second, that deterioration by oxidation and hydration be prevented.

Earlier failures in the effort to make a good powdered milk were due chiefly to destruction of colloidal properties, the protein becoming insoluble. This defect is often found even in the improved products now on the market. To avoid this trouble, soda or other alkaline salts were sometimes added. The addition of such substances gives a brown color to the powder and alters the flavor. A powder made with such an addition may dissolve, but it is hardly fair to call the solution milk. Sometimes added alkali renders the powder less soluble instead of more so, besides injuring both color and flavor.

Since powdered milk is intended as a substitute for fresh milk, the change in milk constituents other than water should be as slight as possible, and nothing should be added in the process of manufacture. The investigations described in the pages which follow were undertaken with a view to determining which machines and methods most nearly fulfill these ideals.

A long series of experiments has shown that the preservation of the colloidal properties of milk constituents demands a process using the lowest possible temperature and exposing the milk to heat for the shortest possible time. Some of the machines now in use fulfill these requirements fairly well and so produce a powdered milk in which the original colloid properties of the milk constituents are almost completely retained.

Drum processes keep the milk in contact with the hot drum only a few seconds; but when they are operated under atmospheric pressure the temperature of the milk rises so high that the casein and albumin are apt to be rendered insoluble. In the case of spray processes, success depends on the way in which the milk is pretreated and on the temperature of the drying chamber. Unless the temperature in these stages is too high, none of the protein coagulates during the process, and the product retains its dispersion properties.

Powdered milk is pretty completely dried, some samples having less than 1 per cent of moisture. Troubles due to bacteria and to enzyme action are seldom met with. The same cannot be said of deterioration from oxidation, which is often observable within a short time in the case of whole-milk powder. The absolute elimination of this trouble has not yet been effected. As oxidation of milk fat is the main trouble, powder made from whole milk deteriorates much more rapidly than that from milk wholly or partly skimmed. For this reason, milk powder from skimmed milk has been more extensively manufactured than that from whole milk.

Recent improvements in processes, however, have produced powdered whole milk which keeps for months and perhaps will keep for years. Manufacturers have thus been able to put on the market a milk powder which is available for infant food. These products are not yet perfect, and a wide field of investigation remains open. In the author's opinion, the goal to be sought in perfecting powdered milk is nothing short of the solution of the entire problem of market milk.

The many advantages which would be offered by a perfect milk powder are obvious. The shipment of perishable fluid milk over long distances would be eliminated, saving not only freight charges but refrigeration costs. Transportation expense for milk powder would probably average not more than one-tenth that for fresh milk, and losses from spoiled milk would be almost entirely avoided.

The regulation of supply according to demand would be enormously simplified. The whole business of city distribution of fluid milk would be eliminated. This distribution involves hardship to the workers because of the inconvenient hours, and entails great expense because of the frequency of deliveries, the overlapping of milk routes, and the cost of pasteurizing and bottling. Lost and broken milk bottles are a considerable item of this expense.

Milk handling under such conditions would involve a short haul in the first place from the farm to a conveniently situated factory. Here the fresh milk would be converted into milk powder and packed in suitable containers of various sizes. Very small containers would not, in general, be needed, because even the

smallest family could use a pound can, since the powder keeps perfectly for a few days after the can is opened. Grocers would stock milk powder just as they do sugar and other non-perishable staples, and families would buy it no more frequently than these, and just as simply. Milk of any desired degree of richness could be prepared as needed. This is no idle dream; the future will see it realized.

Evenson[1] considered it a fraud to use powdered milk as a substitute for market milk. This view may be justified in the present condition of our supply of powdered milk, especially when milk is remade from skimmed-milk powder and unsalted butter. If, however, a perfect powdered whole milk is remade simply by the addition of pure water, there is no reason to condemn it, provided that the powdered milk is perfectly wholesome and the reconstituted milk is the same in every respect as the original milk. If anything is wrong with it, it is the name. It is not fresh milk or pasteurized milk. As long as the nutritive value, flavor, and hygienic conditions are the same as or better than those of ordinary market milk, powdered milk is not to be condemned but welcomed, for the benefit of the public at large and also of the dairy industry. An ideal powdered whole milk should not respond to the test devised by Evenson for distinguishing remade milk from ordinary market milk. So long as the remade milk responds to Evenson's test, the powdered milk cannot be a perfect substitute for market milk.

DEVELOPMENT OF THE INDUSTRY

The first patent on drying milk was Grimwade's English patent of 1855. It was a dough process. The milk, with some alkali added, was evaporated in an open, jacketed pan, with constant stirring, in much the same way as in the oldest methods for making condensed milk. The process was carried further, until the mass had a dough-like consistency. The dough was passed between rollers which made it into ribbons, then further dried, pulverized, and sieved. The process was later improved by substituting a vacuum pan for the open vessel. This process was used for some years with little success. The product could be

[1] Evenson, Oscar L., Jour. Dairy Sci., Vol. V, p. 97.

found on the shelves of groceries and drug stores in the late sixties of the past century. Its quality, however, was not such as to win a ready market, and the successful introduction of sugared condensed milk of the type now so familiar retarded the progress of powdered milk manufacture.

Percy Process.—Samuel R. Percy invented and patented, in 1872, a process of atomizing and drying fluid substances by the use of dried, heated or cooled air or gas. This was probably the first spraying process used in drying liquids. Whether or not it was applied to the drying of milk at that time is not known.

For nearly forty years there was no noticeable progress in the manufacture of powdered milk. In 1895 Robertson spoke of infant foods made from dried milk, probably mixed with cane sugar and cereal flours. Allen referred to "Nutrose" in 1898. This is a food preparation consisting of casein and fixed alkali. Carpenter, in 1898, mentioned the making of dried milk by a German. The product is said to have been well dried; but it did not keep, as the albuminoids decomposed and the fat became rancid. In 1899, Richmond described the manufacture of milk powders, the milk being evaporated to dryness *in vacuo* and granulated. This product contained 40 to 42 per cent of cane sugar.

Stauff Process.—In 1900, Robert Stauff patented a method of obtaining the solid constituents of blood, milk, etc., in the form of a dry powder, by spraying the liquid into a chamber containing heated air. This process was later improved and is now one of the most successful milk-drying processes employed on a commercial scale.

Campbell Process.—In 1901, the Campbell process was patented. In this process milk is placed in an open receptacle heated by a water jacket, and heated air is blown through the liquid. In this way the milk is highly concentrated, and it is then placed in a rotating drum in a current of hot air until it becomes semi-solid. It is then broken into small lumps, forced through a sieve, and thus converted into small granules. It then passes into a canvas drum where it is completely dried by a current of air, after which it is ground.

Wimmer Process.—In 1902, Rucka and his associates described another method of drying milk, invented by Wimmer of Copenhagen. Milk is evaporated in a steam-heated vessel under

reduced pressure with constant stirring. When the water content is reduced to 25 or 30 per cent the milk takes the form of crumbly fragments. These are dried at a temperature below the melting point of butter fat, until the water content is reduced to from 16 to 20 per cent. The mass is then pulverized and further dried at a low temperature, leaving 6 to 7 per cent of water in the powder.

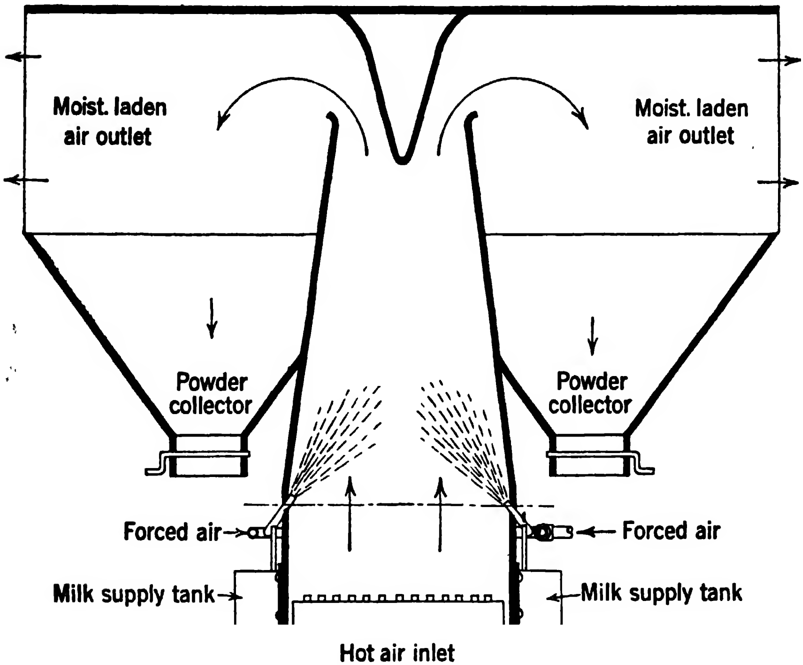
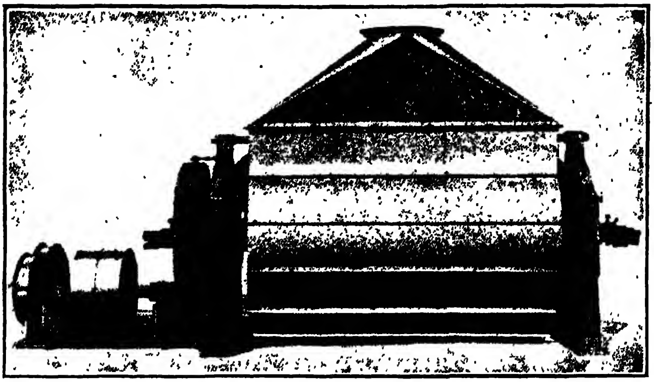


FIG. 46.—STAUFF'S SPRAY DRYING PROCESS.

Ekenberg Process.—Ekenberg, of Sweden, invented a successful milk-drying process in 1899, secured a British patent in 1902, and received United States patents in 1904 and 1905. This was the first drum process patented and is the basis of the present improved drum processes. A rotary drum is heated internally by a current of steam. Milk flows on to the hollow and walls of this drum, then to the cylindrical surface, where it is dried. It is then scraped off. The whole apparatus is so enclosed that it can be operated either at atmospheric pressure or at reduced

pressure. A similar apparatus was invented by Emil Passburg of Berlin.



Manufactured by the Bagley and Sewall Company.

FIG. 47.—CYLINDER SPRAY AND AIR CIRCULATING MILK DRIER, BARKER PATENT.

Just-Hatmaker Process.—At about the same time, another form of drum process was patented by John A. Just, of Syracuse, New York. The patent is dated 1902. This machine consists of

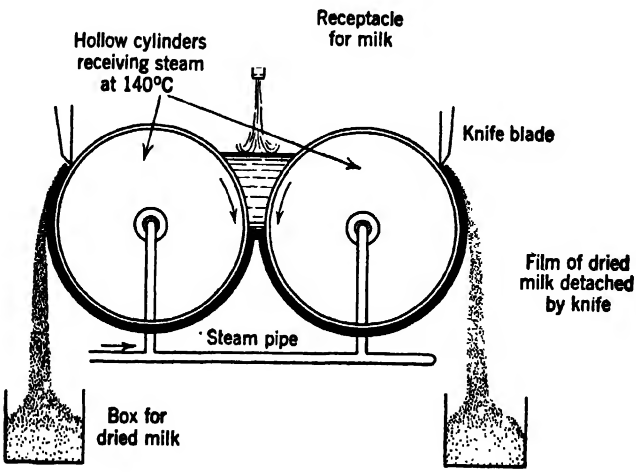
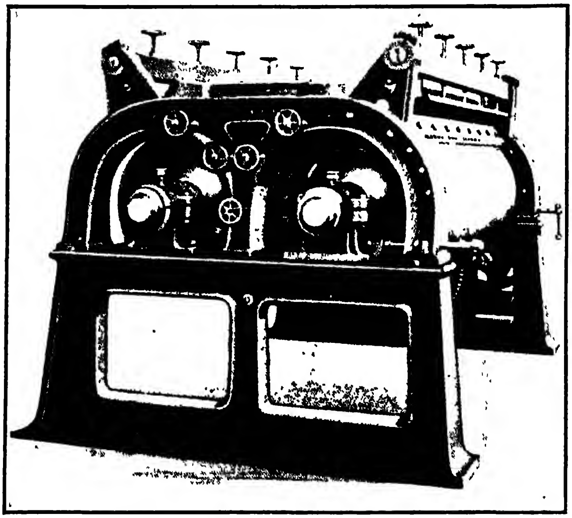


FIG. 48.—JUST-HATMAKER PROCESS.

A double-cylinder open-air drum process.

two hollow metal cylinders arranged to rotate in opposite directions, and so mounted as almost to touch. At first the cylinders

rotated 6 or 7 times per minute. The speed was later increased to 14 rotations per minute so as to decrease the time of contact of the milk with the heated surface. Steam at 2 to 3 atmospheres pressure is introduced into the cylinders. Milk flows from an elevated container into the space between the cylinders, dries on the outer surfaces of the cylinders, is scraped off, further dried, pulverized, and sieved. This patent was purchased, by James R. Hatmaker, and with improvements was patented in England in 1906 under the name of the Just-Hatmaker process.



Manufactured by the Bagley and Sewall Company.

FIG. 49.—DOUBLE DRUM DRYING MACHINE.

Bevenot and De Neveu Process.—The spraying method was applied in drying and powdering milk in a process patented by Bevenot and De Neveu in 1904. The milk is homogenized before spraying. Perhaps this was the first application of the homogenization of milk in the manufacture of milk powder.

Kunick Process.—The Kunick process was patented in 1906 and 1907. It is similar in principle to the Just-Hatmaker process. The milk is preferably condensed before it is spread on the cylinders. Sometimes only one large cylinder is used. In other machines two cylinders of different sizes, mounted parallel and revolving in opposite directions, are employed. Over the surface

of the cylinders is fixed a hood leading to a flue in which is an exhaust fan causing a current of air to flow over the thin film of milk and so aid evaporation.

McLachlan Process.—The Stauff process was modified by John C. McLachlan, and the new process patented in 1905. A tall cylindrical chamber is surrounded by a jacket containing steam coils. Near the top is installed a circular perforated pipe for discharging heated air into the chamber. An atomizing jet is placed on the side of the chamber near the top. A pump forces heated air into the atomizing nozzle. A sliding door at the bottom permits the withdrawal of the powder, and the top is perforated to allow the moisture-laden air to escape. In a later modification, the heated air is discharged into the chamber through a rotating head in the center of the chamber.

Merrell-Soule Process.—Probably the most successful process for making milk powder is the Merrell-Soule process, also known as

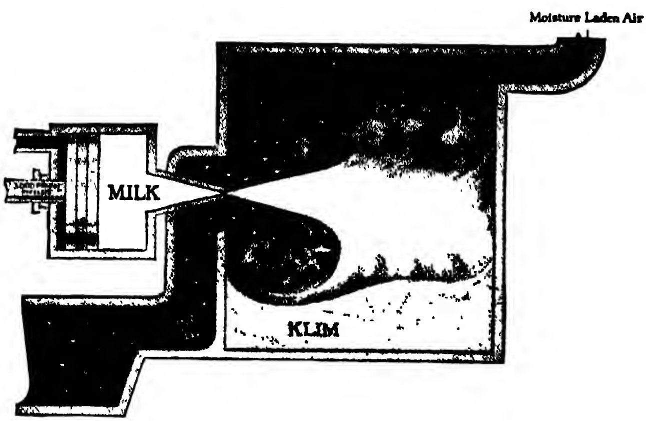


FIG. 50.—SCHEME OF THE MERRELL-SOULE PROCESS.
A high-pressure spray milk-drying process.

the Merrell-Merrell-Gere process and the Trufood process. The Merrell-Soule Company, of Syracuse, New York, purchased the patent secured by Stauff in 1905. L. C. Merrell, I. S. Merrell, and W. B. Gere improved the process and obtained a patent in 1907. Partly condensed milk is sprayed into a drying chamber through a spraying nozzle by means of a high-pressure pump. Purified heated air is blown into the chamber at the same time.

The atomized drops of the sprayed condensed milk dry while in flight and are collected from the floor as a fine powder. A dust collector catches the portion that would otherwise be carried out by the current of air.

Gathmann Process.—In 1906, Louis Gathmann patented a process similar to other drum processes. The drier is made on much the same principle as the common grinding machine. The drum is conical in shape and corrugated on the surface. The adjacent surface against which the cone revolves is made up of spiral grooves. Steam being admitted to the interior of the conical drum, milk is fed on to the larger end. As the cone revolves, the drying milk is kneaded and ground between the two surfaces and carried slowly toward the smaller end of the cone, where it is discharged as dried and ground milk.

Glaxo Process.—Many processes having been invented, the milk-drying industry became well established in both America and Europe. A London firm, the Glaxo Company, started a factory in New Zealand, using a drum process. It is claimed that special precautions taken in manufacture insure a longer keeping period for their product, without serious loss of flavor, than can be shown by other milk powders.

Gabbler-Saliter Process.—This process was patented in 1908. It is a modification of the ordinary drum method, the milk being dried in a thin film on a heated surface. The modification is in the degree of heating, the drum being heated by steam, but only to a temperature below the boiling point of milk. The dried milk coming from the drum is quickly cooled.

Govers Process.—In 1909, F. X. Govers, of Owego, New York, patented another drum drier, consisting of two encased cylinders, operated in vacuum. Continuous discharge valves are provided, permitting withdrawal of the powder without breaking the vacuum in the system.

Lacomte and Lainville Process.—In 1910, a cold-drying process was presented by Lacomte and Lainville before the National Society of Agriculture of France. The principle is the separation of solids of milk by freezing the water only. The milk is frozen in such a manner that the water is not in a solid mass but in the form of snowy crystals. The other constituents of the milk are not frozen, and may be separated in the form of a thick paste, which

can afterward be dried completely at a moderate temperature. At the present writing, the success of this process in practice has not been proved.

Mignot-Plumey Process.—This process was patented in France in 1911. It is another drum system, whose special point is in drying at a low temperature. The milk is condensed before being dried, and immediately cooled. It is then fed into a receptacle in which revolves a small cylinder, which conveys a thin film of condensed milk to the surface of a larger cylinder heated internally by hot water. The large cylinder is covered by a hood connected with an exhaust fan to carry off the moist air. The temperature of the heating water is about 93° C., but that of the heating surface of the cylinder does not exceed 85° C.

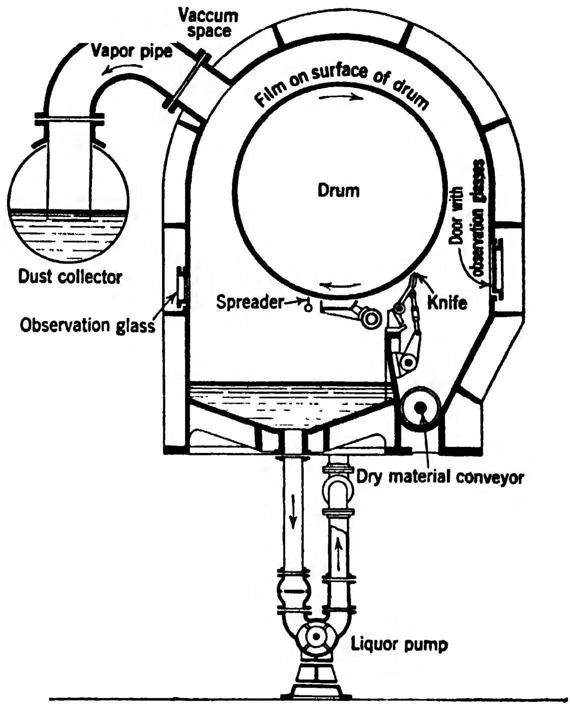


FIG. 51.—BUFLOVAK PROCESS.
A vacuum drum drying process.

Buflovak Process.—O. S. Sleeper secured United States patents on what is known as the Buflovak vacuum drier, in 1911, 1913, 1914, 1915, and 1916. This is probably one of the most successful driers of the drum type ever invented. A polished drum, steam-heated, revolves in an air-tight casing. Milk is fed to the drum by a pan located beneath it. The pan has an automatic overflow for the removal of surplus milk not taken up by the drum. Milk is supplied to the bottom of the casing, and pumped thence to the supply pan. Near the supply pan is an

arrangement which levels off and equalizes the layer of milk on the drum. The dried milk is scraped off by a scraper, broken up by a breaker, and discharged into a receiver. A high vacuum is maintained in the apparatus, permitting rapid evaporation at a relatively low temperature. The actual drying time of the milk on the drum is from six to seven seconds. The operation is continuous.

Gray Process.—Gray and Jensen secured a United States patent in 1913 on a spray process of milk drying. Gray later secured a series of patents on improvements, in 1914, 1915, and 1918. This drier consists of a large cone-shaped chamber, terminating in a discharge opening. The flue for the escape of moisture-laden air is at the top. Milk enters under pressure through a spray nozzle in the center near the top. The heated air is introduced by means of a blower through tangential nozzles around the periphery of the chamber.

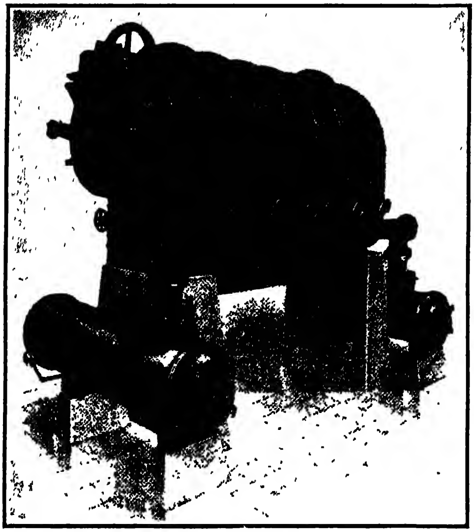


FIG. 52.—BUFLOVAK VACUUM DRUM DRIER.

Rogers Process.—The simplicity of the spray method tempted engineers to modify Stauff's process. C. E. Rogers obtained a patent for a modification of this process in 1917. Spraying nozzles are provided on all four sides of a large drying chamber, near the top. Hot air is blown in near the bottom through upward-pointing openings. Atomized milk falls from a point near the top, through the current of ascending hot air. Spent air escapes through screens near the bottom around the periphery.

Dick Process.—Spray processes involve atomizing the fluid milk into a drying chamber into which a current of hot air is forced. The milk is sprayed either by being forced by a pump through a nozzle under high pressure, or by being pushed out

from the atomizing nozzle by compressed hot air. Dick used centrifugal force to atomize the fluid milk, the principle being similar to that used in centrifugal milk emulsifiers.

Flake Process.—Recently a process of drying skimmed milk has been developed in the United States. Partially condensed skimmed milk is whipped into a froth and spread on a diamond-mesh wire belt which moves through a drying chamber, where heated air is blown on to both surfaces of the belt. Metal fingers or pickers remove the very light and flaky product.

Thus milk drying has developed from the primitive dough system to the present improved drum and spray processes, and the quality of the product has been brought almost to perfection. As has been stated, the earlier attempts were made chiefly with whole milk, and these failed largely because of the quick deterioration of the milk fat. The extensive manufacture of powdered milk from skimmed milk has been brought about by the rapid development of the sweet-cream system of butter making in recent years. The economical disposal of the great quantities of sweet skimmed milk resulting from this method of making butter became an important problem, and the dried product has been successful in finding a market. Later improvements in method have made possible a powder made of whole milk which keeps fairly well, and this has contributed to the stability of the dairy industry.

USE OF POWDERED MILK

At first, this product was used mainly as an infant food. Various commercial uses have been added, and eventually we may expect that it will at least partially replace fluid milk in the general market. It is now much used for milk chocolate. In the cheaper grades, skimmed-milk powder is used; for better qualities, whole-milk powder; while cream powder is employed in some high-grade milk chocolates. Milk powder is also largely used in the manufacture of other forms of sweets, such as caramels, and in ice cream. Bakers use powdered milk in bread and biscuits as a substitute for fluid milk. In the making of macaroni and certain cakes, milk powder replaces eggs, coloring matter being added.

GROWTH OF THE INDUSTRY

Rapid development of the industry has resulted from these and many other uses of milk powder, and it has become an important commercial product. Since the industry is of comparatively recent development, there are no complete statistics of production and trade for powdered milk. In most statistics it is included in condensed milk.

Belgium.—Belgium is known to import some powdered milk, but there are no statistics distinguishing this product from condensed milk.

Denmark.—Denmark has no statistics on production, but her export figures are of interest. A small amount was exported as early as 1912. From 1915 to 1919, inclusive, no powdered milk was exported. In 1920 the export trade revived, with a total of 117,000 lbs. for the year. In 1921 the amount increased to 687,000 lbs. and in 1922 to 1,303,000 lbs. This conspicuous increase is referable to the fact that Denmark is a great butter-producing country and is finding this a profitable avenue of disposal for sweet skimmed milk.

France.—France has no figures for the production of powdered milk, though she undoubtedly does make some. She is essentially a consumer, as is shown by the table of imports and exports of this product.

French Trade in Powdered Milk

(Thousands of Pounds)

Year	Imports	Exports	Year	Imports	Exports
1909	749	...	1917	1024	90
1910	664	38	1918	343	11
1911	863	105	1919	1564	70
1912	965	89	1920	1890	186
1913	1025	135	1921	2655	95
1914	583	...	1922	3079	62
1915	1226	...	1923	2613	187
1916	706	146			

Germany.—Germany shows no statistics on the manufacture of powdered milk, and her figures for imports and exports do not distinguish this product from condensed milk. These trade data are given in the introductory chapter, page 22.

Great Britain and Ireland.—There are no statistics of production for the United Kingdom, which is the world's chief market for all dairy products. England alone accounts for about 75 per cent of the importation of dairy products by all countries. Trade figures for powdered milk since 1909 follow.

TRADE IN POWDERED MILK IN GREAT BRITAIN AND IRELAND

(Thousands of Pounds)

Year	Imports	Exports	Re-exports
1909	1,607	3	108
1910	2,289	32	34
1911	3,277	31	70
1912	4,157	29	168
1913	5,217	9	253
1914	4,214	17	163
1915	5,714	2	21
1916	2,524	...	238
1917	6,202	...	118
1918	10,087	...	1
1919	12,989	3	1139
1920	6,769	281	304
1921	5,963	676	2008
1922	8,828	114	1226

Italy —Trade in powdered milk in Italy has been as follows:

ITALIAN TRADE IN POWDERED MILK

(Thousands of Pounds)

Year	Imports	Exports	Year	Imports	Exports
1909	494	11	1917	362	17
1910	464	32	1918	11	1
1911	546	45	1919	295	7
1912	472	55	1920	710	21
1913	490	77	1921	240	36
1914	372	93	1922	717	35
1915	414	96	1923	456	59
1916	395	80			

Holland.—Holland is among the important European countries producing powdered milk. There are no published data to show her production. Only export figures are available, and these are given in the following table.

EXPORT OF POWDERED MILK FROM HOLLAND

(Thousands of Pounds)

Year	Whole-milk Powder	Skimmed-milk Powder	Not Specified
1917	....	....	9474
1918	....	....	3761
1919	1914	8823	
1920	5708	7649	
1921	9722	3007	
1922	6975	3710	
1923	9057	4833	

Holland is the greatest exporter of milk powder in Europe, and this indicates that she is also the greatest producer.

Norway.—Before the war Norway was an exporter of all dairy products. Since the war she has exported less and imported more. The table shows the trade in powdered milk.

NORWEGIAN TRADE IN POWDERED MILK

(Thousands of Pounds)

Year	Imports	Exports	Year	Imports	Exports
1909	7	102	1917	...	321
1910	18	184	1918	...	1
1911	32	596	1919	160	35
1912	50	430	1920	133	14
1913	57	423	1921	156	6
1914	29	130	1922	...	57
1915	..	409	1923	144	55
1916	..	440			

Sweden.—Trade statistics for Sweden indicate that she is a producer of powdered milk, but no figures for production are available. Import and export figures are given in the table.

SWEDISH TRADE IN POWDERED MILK

(Thousands of Pounds)

Year	Imports	Exports	Year	Imports	Exports
1909	5	216	1917	...	124
1910	4	530	1918	...	...
1911	2	578	1919	191	263
1912	7	491	1920	9	260
1913	8	566	1921	31	330
1914	20	692	1922	140	208
1915	18	413	1923	243	...
1916	8	533			

Other European Countries.—Russia, Switzerland, and other European countries do not give any statistics of the manufacture of powdered milk or of the trade in this product. Most European countries are probably producing some. Holland is the only stable exporter of powdered milk. Denmark is taking a leading place in exporting skimmed-milk powders. England, Germany, and France are the chief consumers. In Germany there was a great scarcity of dairy products after the war, and powdered skimmed milk was imported, to be made into filled milk to supply the deficiency.

Canada.—Canada produced a considerable amount of milk powder to supply European demand due to the war. Financial

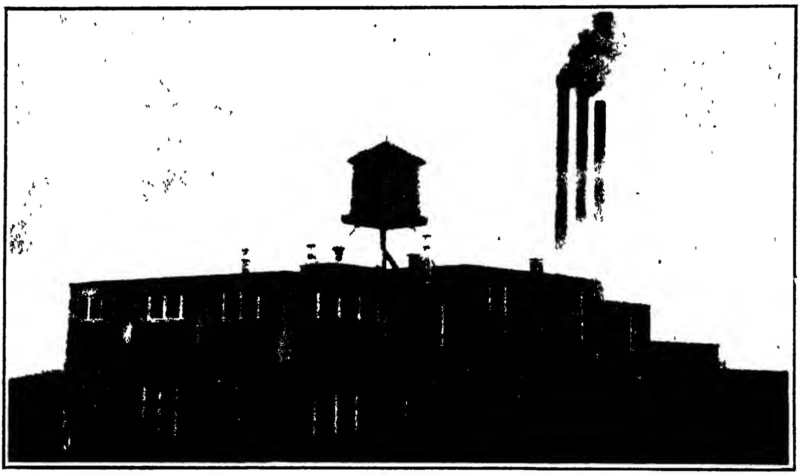


FIG. 53.—SPRAY-PROCESS MILK-DRYING FACTORY.

Merrell-Soule Company.

depression in Europe curtailed this trade. The table that follows shows Canadian production for several years. What proportion of this was exported the statistics do not show.

PRODUCTION OF POWDERED MILK IN CANADA

(Thousands of Pounds)

1917	3980	1919	6789	1921	1703
1918	5616	1920	7575	1922	1430

United States.—The United States produces about one-third of the dairy products of the world. The dairy industry is well developed here, both scientifically and industrially. European inventions for use in the manufacture of powdered milk have been perfected and operated in the United States. Before the war, powdered milk was an insignificant item compared with other dairy products, and no separate data are given for it in the

FIG. 54.—A DRUM MILK DRYING FACTORY.
The Glaxo Co.

statistics. Available figures for production and export are given in the table.

PRODUCTION AND EXPORT OF POWDERED MILK BY THE UNITED STATES

(Thousands of Pounds)

Year	Powdered Milk Produced	Powdered Cream Produced	Powdered Milk Exported
1917	25,800	...	....
1918	30,200	...	....
1919	42,300	...	....
1920	52,200	309	3172
1921	4,200	100	9443
1922	5,600	100	6190
1923	6,600	328	2437
1924	7,887	1018	
1925	8,931	339	

The great production during the period from 1917 to 1920 was undoubtedly due to the increased demand from European countries, caused by the shortage in dairy products in Europe resulting from the war. The steady increase since 1921 is due to growing home consumption. This seems to show that the industry has become stabilized in the United States and has an assured future.

Other Countries.—Australia and New Zealand are also manufacturing milk powder. The former has no statistics available. For New Zealand, statistics of production have been published since 1919, and show a steadily increasing amount, most of which is exported.

PRODUCTION OF POWDERED MILK IN NEW ZEALAND

Year	Thousands of Lbs.
1919	3,708
1920	11,916
1921	14.112

The powdered milk industry is beginning to develop in Japan. Six condensed milk factories have installed milk-drying machines (1927). The production is as yet not considerable, but there is a prospect of development.

COMPOSITION OF POWDERED MILK

Since powdered milk is simply milk from which the water has been removed, it should contain all the constituents of fresh milk except water, in the same proportions as the original milk. Under some conditions of manufacture, however, some of the milk constituents, especially albumin and calcium salts, are liable to alteration and loss.

Fat.—The fat content of milk powders varies greatly. Obviously, this may be due to variation in the fat content of the original milk; but, because fat deteriorates easily in powdered milk, a part of the fat is sometimes removed before the milk is dried. The fact that much skimmed milk is made into milk powder has been mentioned, and this product has, of course, little fat. Hunziker quotes, from the United States Bureau of Markets Reports

for 1920, the following figures for various milk powders produced in 1918 and 1919. Skimmed-milk powder: 1918, 25,432,000 lbs.; 1919, 33,076,000 lbs. Whole-milk powder: 1918, 4,164,000 lbs.; 1919, 8,661,000 lbs. Cream powder: 1918, 654,000 lbs.; 1919, 592,000 lbs. The milk powders used commercially are mostly from skimmed milk. The powders made from whole or partly skimmed milk are, in general, used for infant foods.

Lecithins are said to be altered by the drying process, but the exact nature of the change is not known.

Protein.—The apparent solubility of casein in milk powder is often low. This is especially the case with old powders, those having high moisture, and those made by the dough and drum processes. Casein is always present, and in comparatively constant percentage.

Albumin is apparently absent in some makes, at least in its natural soluble condition. This is because the milk has been subjected to a high temperature in the process of manufacture.

Soluble proteins are present to a greater or less extent.

Ash.—The proportion of ash to the other milk solids is nearly constant and is nearly the same as in fresh milk. When alkali is added, the ash is, of course, increased. Loss of citrates has been found in some cases, and calcium phosphate may be rendered insoluble if the heat of manufacture is too high or long-continued.

Lactose.—In general, lactose seems to suffer no alteration in the process of drying. Added alkali is apt to combine with lactose, but such addition is now infrequent. In older processes in which the milk was subjected to high or long, continued heat, the lactose was often caramelized.

Sucrose.—This is not a normal constituent of powdered milk, but a foreign substance added in some cases for special purposes. Powdered milk intended for use as infant food sometimes has sucrose added to supply the deficiency in carbohydrates. Where this is done, the amount of sucrose is usually 1 to 2 per cent added to the fresh milk, making from 10 to 15 per cent in the dry product. In extreme cases, the powder may contain 50 per cent sucrose.

Composition of Powdered Milk.—The table following shows the results of analyses of samples of milk powders found in the Japanese market, coming from various parts of the world.

COMPOSITION OF POWDERED MILK FOUND ON THE JAPANESE MARKET

Sample No.	Moisture	Protein	Fat	Lactose	Ash	Sucrose
1	1.15	24.16	27 77	40.78	6.14	.....
2	1.53	21.62	25 85	45.42	5.59	.....
3	2.43	20.05	16 81	39.23	6.05	15.44
4	3.17	21.08	25 02	45.47	5.27	.....
5	5.78	28.18	5 80	52.88	7.36	.....
6	4.18	19.74	23 20	47 58	5.30	.....
7	4.60	19 61	24.25	46.39	5.16	.....
8	2.12	22 20	19.10	39.01	5.43	12.14
9	2.20	12.10	3.85	29.17	3.33	49.35
10	2.59	12 06	7 95	27 52	3.34	46.53
11	7 51	29 12	2.26	53.73	7.38	.....
12	0.50	22 60	18.89	40 66	5.77	11.58
13	0 43	22 02	18 76	39.68	5.93	13.19
14	1 56	20 37	18.40	39.02	5.71	14.94
15	1 50	21 88	18 83	38.39	5.81	13.59
16	1 68	22 78	18 72	38 28	5.90	12.65
17	1.61	20 72	17 41	38.14	5.64	16 48
18	1 67	22 11	18 57	37.59	5.80	14.27
19	1.07	20 28	25 80	37 41	5.49	9.97
20	1 46	18 53	24 83	35 36	5.13	14.69
21	1.29	19 61	24 22	35 31	5.35	14.23
22	1 29	18.80	22.96	35 13	5.21	16.61
23	1 04	22 51	27.59	43.10	5.76	.....

Among these samples are a number of brands made by different processes, and some products of experimental manufacture. Eleven commercial brands are included in the series: four made by spray processes; four, by drum processes; and three, by dough processes. Most of the eleven are partly skimmed products. Among brands of milk powder intended for infant feeding, Klim, Lactogen, Bonalac, and Homogen are made from whole milk. Partly skimmed products include Kintaro, Morinaga, and Glaxo brands. The manufacturer of the Kintaro brand has recently begun to market a whole-milk product. Darigold, Oshidori, Dog, and Hinode brands are either entirely or mostly skimmed-milk products. Of late, whole-milk Darigold may also be found in the Japanese market.

Skimmed-milk powders contain about 5 per cent fat; whole-milk powders, about 25 per cent; and partly skimmed products around 20 per cent. Apparent variations in other constituents are due largely to added sucrose. The moisture content varies

even with the same brand. Spray-process powders generally have less moisture than those made by the other methods.

The protein content is naturally highest in unsweetened skimmed-milk powders, and lowest in sweetened whole-milk products, varying from 12 to 28 per cent. Unsweetened whole-milk powder has about 23 per cent on an average. Heat-coagulable protein, chiefly lactalbumin, often coagulates out in process. Experiment showed that some brands, especially those made by spray processes, retained this component unchanged. Experimental work with a spray machine showed that careful control of temperature during the whole process of manufacture may retain the lactalbumin and other heat-coagulable proteins almost without change. The same samples used for the general analysis were also analyzed for protein, with the results shown in the following table.

Analyses of Proteins in Powdered Milk

Sample No.	Total Protein	Acid-coagulable	Heat-coagulable	Soluble
1	24.16	19.03	2.62	2.50
2	21.62	17.91	2.41	1.30
3	20 05	16 97	2.27	0.81
4	21.08	20 10	trace	0.98
5	28.18	26.80	trace	1.38
6	19.74	18.49	trace	1.25
7	19.61	17.86	nil	1.74
8	22.20	21.71	trace	0.49
9	12.10	10.81	nil	1.29
10	12.06	11.12	nil	0.94
11	29.12	23.94	trace	5.18
12	22.60	17.24	2.46	2.90
13	22.02	17 24	3.04	1.74
14	20 37	15.59	2.23	2.55
15	21 88	16.26	3.22	2.41
16	22.78	15.90	3.35	3.53
17	20.72	15.23	2.55	2.95
18	22.11	16.57	2.95	2.59
19	20.28	15.72	2.59	1.97
20	18.53	14.92	1.96	1.65
21	19.61	16.39	0.89	2.32
22	18.80	16.70	1.07	1.03
23	22.51	19.12	2.14	1.25

The heat-coagulable protein varied from nothing to 3.35 per cent. It must have been destroyed in some samples by high

temperature at some stage of manufacture. Acid-coagulable protein, i.e., casein, varied from 10.08 to 26.80 per cent, the former being the percentage for the most heavily sweetened product, the latter for unsweetened skimmed-milk powder. Unsweetened whole-milk powder contained about 19 per cent. Soluble protein varied from 0.50 to 5.18 per cent. In the latter case there was evidence of added alkali.

The percentage of lactose varied, because of the variations in moisture, fat, and added sucrose. It was highest in unsweetened skimmed-milk powders and lowest in sweetened products, the extremes being 63.73 and 27.52 per cent. Unsweetened whole-milk powders averaged about 42 per cent, ranging from 40 to 44 per cent. No alteration in the nature of the lactose was noticeable. The form of lactose present in powdered milk is the β-modification. It is amorphous in most cases.

The ash was comparatively constant, varying from 3.33 per cent for the heavily sweetened skimmed-milk product to 7.39 for unsweetened skimmed-milk powders. Unsweetened whole-milk powders contained about 6 per cent.

Many brands of powdered milk found in the Japanese market contained added sucrose; one brand, which seemed to be a dried sweetened condensed milk, as much as 49.35 per cent. Most of the sweetened powders had about 14 per cent sucrose. Those containing no sucrose were the Klim, Kintaro, Lactogen, Darigold, Bonalac, Homogen, and Hinode brands.

Hunziker [2] has compiled analyses of powdered milk from various sources. A table showing his results is given on page 264.

These analyses indicate that powders made in Europe usually contain more moisture than American brands. The processes employed in manufacturing these samples are not stated. Since, however, the analyses made by Merrell-Soule Co. show the lowest moisture content in every class of powdered milk, and since their products are manufactured by a spray process, it may be said that the powdered milk made by the spray system is drier than that manufactured by other systems. The drum system is more commonly used in European powdered milk plants. It is noticeable that the fat content of powdered skimmed milk is lower in analyses

[2] Hunziker, O. F., Condensed Milk and Milk Powder, 4th ed., p. 479.

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15	21 88	16.26	3.22	2.41
16	22.78	15.90	3.35	3.53
17	20 72	15 23	2.55	2.95
18	22.11	16.57	2.95	2.59
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[2] Hunziker, O. F., Condensed Milk and Milk Powder, 4th ed., p. 479.

compiled by Hunziker than in the skimmed-milk samples collected on the Japanese market.

COMPOSITION OF POWDERED MILK

(Compiled by Hunziker)

Analyses Made or Reported by	Water	Fat	Protein	Lactose	Ash	Sucrose
Whole-milk Powders						
Richmond..........	6 39	27.35	27.48	31 42	6.00	
Richmond	4 92	27 98	24.59	34.16	6 24	
Richmond..	4 74	29 16	26.66	32 24	5 63	1.25
C. Huyge....	3 62	26 75	32.06	31 90	5.67	
Larsen and White...	1 40	29 20	26 92	36.48	6 00	
Otakar Laxa	4 07	25 00	24 84	35 75	6 20	3.13
Merrell-Soule Co..	1.50	28 20	26.67	37 88	5.75	
Partly Skimmed Milk Powders						
Richmond....... ..	5 15	19 90	31 10	34.90	7 11	
C. Huyge	5 01	15 26	38 39	34 67	6.67	
C. Huyge	8 30	13 00	30 57	48.85	7 28	
Larsen and White..	5 00	15.12	33 30	39 70	6 90	
Otakar Laxa	5 46	21 96	25 69	40 93	5 74	1 16
Otakar Laxa ...	4 80	17 13	29 88	40 72	6 84	5 08
Otakar Laxa ...	5 85	15 72	30 95	40 67	6 06	1.46
Merrell-Soule Co.	2 12	14 20	32 26	44 41	7.01	
Skimmed-milk Powders						
Richmond.........	3 55	2.55	35 45	45 60	7 89	2.80
C. Huyge . . .	7 40	1 00	37 28	46 30	8 00	
Larsen and White.	7 00	1 00	37 00	47 00	8 00	
Otakar Laxa .. .	7 15	1 57	33 29	47 23	8 03	
Stocking...	2 40	1 35	37 70	49 94	8 21	
Mojonnier Bros ...	3 39	1 25	33 94	50 88	7 87	
Mojonnier Bros. .. .	1 72	1 15	35 01	52 24	8 03	
Mojonnier Bros. . .	1 00	1 97	34 75	51 92	8.24	
Cream Powders						
Merrell-Soule Co....	0.80	50.40	19 19	25.45	4.16	
Merrell-Soule Co. ..	0 66	65 15	13 42	17.86	2.91	
Merrell-Soule Co. ...	0.56	71 15	11 12	14 74	2.43	

In the above analyses, the sucrose content is very questionable.

Coutts[3] compiled analyses of powdered milk made by a number of analysts on various brands. He indicated the approximate dates of analysis, and the results are listed accordingly. The table gives an idea of the changes that have taken place in the manufacture of powdered milk.

COMPOSITION OF POWDERED MILK COMPILED BY COUTTS

Analyses of Skimmed-milk or Partly Skimmed-milk Powders

Year	Moisture	Fat	Protein	Lactose	Ash	Remarks
1904	5.01	15.26	38 39	34 67	6.67	Half-cream.
1905	5.00	15.10	33 30	39 70	6 90	Hatmaker milk.
1905	2.30	16.65	28 57	45.18	7.30	Three Star Swiss Dairy M.
1905	8.96	0 57	30.59	48.62	8 10	Gallak.
1906	5.40	19.20	21.87	47.43	6.60	Ekenberg.
1906	3.55	2.55	35.45	45.60	7 89	2.8 per cent sucrose.
1906	5.15	19 90	31.10	34.96	7.11	
1909	8.16	1.73	33.84	49 35	6 87	Machine-skimmed.
1909	5 31	6 63	29 14	52.57	6 35	Half-skim powder.
1909	8.54	1.31	32 71	50.24	7 29	Skimmed-milk powder.
1910	7.00	1.00	37.00	47.00	8 00	Hatmaker, skimmed.
1910	6.50	1.00	36 00	49.00	7 50	Ekenberg, skimmed.
1912	4.58	16 00	30 90	41 54	6 98	Cow and Gate.
1912	4.76	1 86	33 75	51 20	8 43	Cow and Gate.
1912	7 30	1 04	32 85	51 40	7 41	Trumilk.
1912	7 30	0 34	32 15	52.83	7 38	Norwegian, separated.
1912	7 75	0 86	35 72	48 41	7 26	Dutch, separated.
1912	5.45	0 35	31 96	54.07	8 17	Dutch, separated.
1912	8 00	0 80	34 61	48.43	8 13	English, separated.
1912	6 86	1 00	34 64	49 62	7 88	American, separated.
1912	7.36	0.73	34 64	49 72	7 55	French, separated.
1913	2.81	2.10	33 51	53 43	8.04	
Milk Powders Made from Skimmed Milk						
1913	2.29 to 10.87	0.67 to 3.40	30.69 to 37 23	45.65 to 52.58	7 00 to 9.66	Extremes out of 50 samples. Government Laboratory.
Milk Powders Made from Impoverished Milk						
1913	5.00 to 6.50	4.73 to 21.92	25.01 to 32.25	39.28 to 49.51	6.40 to 7 80	Extremes out of 7 samples. Government Laboratory.

[3] Rept. to the Local Govt. Board, Food Rept. No. 24, 33.

Composition of Powdered Milk Compiled by Coutts

Analyses of Full-cream Powders

Year	Moisture	Fat	Protein	Lactose	Ash	Remarks
1899	......	15.20	15.10	21.70	3.30	42.5 per cent sucrose.
1899	......	13 50	14.90	21.30	3.20	40.5 per cent sucrose.
1904	3.62	26.75	32.86	31.10	5.67	
1904	3.40	26.90	28.50	35.20	6.00	Defiance Brand.
1904	2.70	27.97	25.60	37.21	6.25	
1904	.....	28.76	26.15	38.19	6.70	Calculated on dry materials.
1905	1.40	29.20	26.92	36.48	6.00	Hatmaker milk.
1905	5.51	23.75	24.71	36.72	6.49	Gallak.
1905	.....	30.00	28.66	35.34	6.00	Garstang Creamery Co.
1906	4.80	28.50	24.30	36.80	5.60	Mean of 5 analyses.
1906	6.40	24.80	14.46	48.84	5.50	"Steriloid."
1906	6.39	27 35	27.48	31.32	6.00	
1906	4.92	27 98	24.59	34.16	6.24	1.25 per cent sucrose.
1906	3.30	23.97	26.38	37.32	6.19	1.53 per cent sucrose.
1906	4.74	29.16	26.66	32.24	5.63	
1906	6.03	25.60	23.84	32.83	6.44	2.00 per cent sucrose.
1906	5.65	23.42	25.48	38.99	6.46	
1909	4.76	41.28	21.31	28.39	4.26	"Cream" powder.
1909	6.23	24.28	24.27	39.18	5.84	Full-milk powder.
1909	4.90	27.00	26.20	36.30	5.60	Defiance Brand.
1909	5.50	23.10	27.20	38.40	5.60	Lak-Cit.
1909	3.50	27.40	22.20	41.00	5.90	Glaxo.
1911	1.20	22.89	23.79	31.63	5.48	37 samples of full milk p.
	to	to	to	to	to	
	10 04	32.14	34.09	45.13	7.54	
1911	2.39	28 46	23.83	39.50	5.82	Glaxo.
1911	2.00	26.90	27.80	37.40	5.90	Trumilk.
1912	3.36	25.00	27.50	27.82	6.32	Cow and Gate.
1912	1.46	30.00	27.69	35.28	5.57	Trumilk.
1912	1 89	27.00	24.62	40.94	5.55	Glaxo.
1912	4.43	24.00	24.11	41.23	6.33	Dutch full-cream.
1912	5.52	26.87	23.92	38.10	5.59	English full-cream.
1912	4.36	23.55	25 62	40.72	5.72	French full-cream.
1912	3.70	29.70	26.79	34.48	5.33	Defiance Brand (N. Z.)
1913	4.29	25.24	25.16	38.99	6.31	Cortland.
1913	4.91	29.64	24.08	35.42	5.95	Adams.
	3.53	25.17	24.78	40.27	6.25	Konigsberg.
1913	1.85	22.58	22.27	33.26	5.44	Extremes of 26 samples.
	to	to	to	to	to	
	6.10	31.28	27.73	41.39	7.58	

Prior to 1900, the product of the European powdered milk industry seems to have been a heavily sweetened one. Analyses made since 1900 do not show the sweetened product, except in a few cases reported by Richmond; and in these the amount of sucrose is too small to be due to intentional addition. Sweetened powders are undoubtedly manufactured even at present, as the trade statistics show the import and export of such products in European countries.

Dobbie,[4] of the Government Laboratory of England, reports analyses of commercial powdered milk.

COMPOSITION OF POWDERED MILK REPORTED BY DOBBIE

Sample No.	Moisture	Fat	Protein	Lactose	Sucrose	Ash
6	3.56	25.25	25.37	36.44	0.35	6.75
11	2.82	26.87	25.36	39.09	....	5.78
17	4 20	31.28	22 88	35.72	....	5.75
34	2.78	25.86	24.50	41 04	.. ..	5.64
36	4.47	29.88	24.28	35 37	....	5.67
37	2 07	25.23	24.47	41 39	.. ..	5.89
39	4.29	26.88	23 90	35 13	.. .. .	7.58
40	4.98	29.62	23 55	35.95	....	5.44
41	5 79	27 21	22.49	35.15	2.58	5.89
42	4.90	28 67	22.27	34 77	2.94	5.70
50	1.85	28 12	23 42	39.36	....	5.80
51	5 48	24 98	25 36	37 66	....	5.78
53	2 50	26 36	27 75	37.08	....	6.00
54	6 10	23 01	23 48	37.42	2.90	6.40
61	4.59	26 38	23 32	36.12	Trace	6.49
62	5.30	22.58	26 51	35.83	Trace	6.40
63	5.24	26.85	24 85	35.98	....	6.59
64	5.48	25.06	26.00	38.13	....	5.78
69	2.54	28.08	25 16	35.84	....	6.52
71	5.39	22 65	23.81	38.83	1.95	6.54
72	4.16	26.77	25.10	36.88	....	6.01
73	4.91	24.35	23.02	38.35	....	6.17
74	4.36	27 37	25.27	36.73	....	5.81
78	5.75	26.34	24.40	36.73	....	6.55
79	4.90	29.60	25.99	33.26	....	5.45
86	3.84	26.66	23.54	37.29	....	6.64

[4] Dobbie, James J., Rept. to Local Govt. Board, Food Rept. No. 24, 157.

Composition of Partly Skimmed and Skimmed-milk Powders Reported by Dobbie

Sample No.	Moisture	Fat	Protein	Lactose	Sucrose	Ash
0	5 74	1 47	34 11	50 88	....	8 26
1	6 23	1.45	31 78	51 45	....	7 35
2	6 68	1 20	32 30	49 55	0.28	8.19
3	6 19	1 50	32 12	51 25	....	7.31
4	4 22	1 45	32 23	50 83	0.99	9 21
5	6 36	3 40	31 92	48 50	....	7.60
7	3 84	1 60	32 09	52 58	0.53	8 48
8	5 78	1 95	32 26	49 67	....	8 55
9	4 45	1 90	32 96	52 17	...	7 62
10	6 25	1 49	31 00	49 96	0.60	9 33
12	4 58	0 95	32 60	52 58	....	8.30
13	6 83	1 85	32 02	49 06	....	8 26
15	6 11	0 95	31 77	51 12	...	7 96
16	6 75	0 85	32 56	50 88	0.30	8 38
18	4 96	1 37	31 13	50 45	...	9 66
19	4 94	1 47	32 85	52 04	..	8 18
20	4 08	2 13	34 45	49 08	0 26	9 56
21	6 25	1 73	32 96	49 19	..	8 58
23	7 28	1 77	31 33	49 06	..	8 78
24	5 70	2 35	33 31	50 03	.	7 91
25	5 35	0 85	32 50	52 00	..	7 83
26	8 07	1 55	31 74	49 17	.	7 48
27	7 73	1 35	32 26	50 38		7 30
28	0 99	1 95	33 58	47 86	...	8 68
29	5.78	1 14	32 89	51 76		8 09
30	6 17	7 14	28 91	46 32	3 85	6 89
31	7 88	1 77	33 59	48 78		7 94
33	2 29	2 12	36 18	50 74		8 14
35	8 60	0 67	32 25	49 59	.	7 54
38	4 76	2 13	35 48	45 14	0 86	9 28
45	8 00	1 55	32 59	47 13	1 68	8 20
46	2 50	1 87	37 23	50 18		8 25
47	5 67	2 25	35 57	47 25	1 08	8 66
48	8 73	0 70	31 55	49 76		7 43
49	4 80	3 40	32 29	50 56		7 89
52	6 60	1 68	34.52	49 52	1 67	7 90
55	7.73	1 50	34 23	46 48	0 80	8.63
56	6 00	21 92	25 01	39 28	1 84	6.40
57	8 10	1 30	32 51	49 72		7 70
58	6 50	16 34	28 42	42 29	.	6 60
59	7 50	2 90	33.24	46 44	.	7 00
60	5 00	11 74	29 76	44 82	....	7.10
66	9 18	1 40	31 09	48 26	...	7.78
67	5 48	1 30	32 89	51 75	....	8.12
68	7.19	1.07	32 08	49 42	....	7.54
70	4.64	0 85	32 35	52 15	...	8 38
75	5 64	18 25	28. 18	42 44		6.68
76	5 40	11.46	29 63	43 87	0.77	7.10
77	5 40	4 73	32 25	49 51		7 80
80	6 95	1 65	34 07	47 03	0.93	8.10
81	7 58	1 70	33 69	45 65	..	8.33
82	7 24	0 90	33 50	47 06	...	8 64
83	6 07	1 50	33 60	47 96	...	8 16
84	7.06	1 67	33 64	46 68	...	8 35
85a	10.87	0 70	30 69	47 60	0.72	7.18
85b	5 04	0 70	33 68	51 11	....	7.69
87	5.75	1.45	32.03	49.62	....	9.10

The different brands and makes of powdered milk in the London market are comparatively constant in composition. Except in a few cases, sucrose is not added in the manufacture of powdered milk. Even in the samples reported to contain sucrose, the amount is so small that the object of adding it is very doubtful. The moisture content, in general, is a little too high for a successful milk powder.

The ashes of the samples analyzed at the Government Laboratory were examined, and partial analyses of them were made, with the following results:

Ash of Powdered Milk Prepared from Whole Milk, Reported by Dobbie

Sample No.	Insoluble in Water	Soluble in Water	Alkalinity Ash Soluble in Water as Na_2CO_3	Chloride as NaCl	CaO	P_2O_5	Insoluble in Dilute Acid
6	3.86	2.89	0.10	1.51	1.29	1.66	
11	3.88	1.89	0.13	0.93	1.37	1.68	
17	3.61	2.14	0.29	0.94	1.23	1.46	
34	3.86	1.78	0.13	0.75	1.28	1.71	
36	3.58	2.09	0.13	1.04	1.23	1.50	
37	3.89	2.00	0.11	0.69	1.31	1.71	
39	4.49	3.09	0.24	1.60	1.36	1.66	
40	3.28	2.16	0.22	1.04	1.20	1.38	
41	3.80	2.09	0.16	0.86	1.44	1.61	
42	3.80	1.90	0.13	0.98	1.40	1.59	
50	4.00	1.80	0.13	0.69	1.30	1.62	
51	3.69	2.09	0.15	1.38	1.33	1.52	0.02
53	4.20	1.80	0.13	0.98	1.38	1.77	
54	4.00	2.40	0.26	1.27	1.66	1.55	0.02
61	4.09	2.40	0.11	1.56	1.31	1.57	0.02
62	4.20	2.20	0.24	1.15	1.34	1.73	
63	3.90	2.69	0.26	0.92	1.36	1.70	
64	3.90	1.88	0.26	1.44	1.75	1.77	
69	4.13	2.39	0.18	1.38	1.41	1.69	0.04
71	4.23	2.25	0.21	1.35	1.70	1.69	0.02
72	3.86	2.15	0.17	1.27	1.34	1.74	0.04
73	3.91	2.26	0.18	1.40	1.31	1.61	0.07
74	3.86	1.95	0.18	1.30	1.34	1.58	0.04
78	4.10	2.45	0.23	1.59	1.36	1.60	
79	3.80	1.65	0.13	0.87	1.29	1.68	
86	3.95	2.69	0.26	1.53	1.52	1.70	0.02

Ash of Powdered Milk Prepared from Impoverished and Skimmed Milk, Reported by Dobbie

Sample No.	Insoluble Ash	Soluble Ash	Alkalinity as Na_2CO_3	Chloride as NaCl	CaO	P_2O_5	Insolubl in Dilute Acid
0	4.84	3.42	0 22	1 59	1.74	2.24	
1	4 68	2 67	0 16	1.55	1.62	1.96	0.02
2	4 87	3 32	0 16	1 17	1.79	2.17	
3	4.57	2 74	0 19	1.52	1 57	1.95	0.04
4	5.52	3 69	0 64	1 84	1.71	2.19	
5	4.80	2 80	0 13	1 37	1.62	2 06	0.02
7	5 32	3 16	0 19	1 91	1.77	2 20	
8	5 11	3 44	0 16	1 92	1 81	2.17	
9	4 41	3 21	0 16	1 56	1 73	2.00	
10	5 71	3 62	0 42	1 70	1.75	2 21	
12	5 23	3 07	0 26	1 73	1 79	2.25	0.03
13	5 28	2 98	0.21	1.62	1 71	2.21	
15	5 12	2 84	0 21	1 63	1.78	2 19	0.02
16	5 09	3.29	0 26	1 75	1.64	2.15	0.01
18	5 60	4 06	0 79	1 86	1 71	2 28	
19	4.93	3 25	0 26	1 75	1 84	2 22	0.03
20	5.28	4 28	0.37	2 34	1 65	2 08	
21	4.95	3 63	0 11	1 75	1 75	2 14	
23	5.22	3 56	0 24	1 81	1 82	2 12	
24	4.96	2 95	0 16	1 56	1 72	2 12	
25	4.92	2.91	0 16	1 56	1 80	2 14	
26	4.85	2 63	0 16	1 51	1 54	1 97	0.01
27	4.37	2 93	0 16	1 45	1 52	1.98	
28	5.14	3 54	0 26	1 99	1 70	2 09	0 02
29	4.96	3 13	0.16	1 75	1 74	2 14	0.03
30	4.48	2 41	0 16	1 46	1 54	1 91	
31	5 24	2 70	0 26	1 44	1 42	1 71	
33	5 44	2 70	0 13	1.33	1 92	2 43	
35	4 85	2 69	0 11	1 44	1 76	2 19	
38	5 84	3 44	0 18	2 08	1 83	2.14	
45	4 70	3.50	0 11	1.87	1 78	2.16	0.02
46	5 20	3 05	0 13	1 33	1 91	2 44	
47	4 78	3 88	0 13	1 96	1 84	2 11	
48	4 69	2 74	0 16	1.61	1 68	1 99	
49	5 00	2 89	0 16	1 73	1 76	2.17	0.02
52	4 60	3 30	0 11	1.73	1 71	1 94	
55	4.99	3 64	0 11	2 05	1 77	2 07	
56	4 20	2.20	0 16	1 15	1 62	1 61	0.02
57	4.30	3.40	0 16	1 73	1.75	1 95	
58	4.10	2 50	0 16	1 15	1.56	1 75	
59	4 60	2 40	0 13	1.21	1 64	1 98	0.03
60	4 60	2 50	0.16	1.50	1 64	1 94	
66	4 89	2 89	0 23	1 56	1 72	2 07	0.04
67	5 13	2 99	0 23	1 76	1.78	2 22	0.04
68	5 15	2.39	0 23	1.56	1 87	2 11	0.04
70	5.49	2.89	0 18	1 67	1.86	2 32	0.06
75	4 21	2 67	0 18	1.21	1 51	1.73	
76	4 50	2 60	0 18	1 62	1.51	1.93	0.01
74	5 05	2 75	0 26	1 65	1.76	2.31	0.04
80	4 70	3 40	0 24	1 82	2.20	2.07	0.01
81	5 29	3.04	0 16	1 59	1 88	2.18	0.02
82	5 45	3 19	0 21	1 73	1.79	2.25	0.01
83	4.93	3 23	0 16	1 90	1 81	2.25	0.08
84	4.97	3 38	0.18	1 90	1 79	2.10	
85a	4.04	3.14	0.32	1 30	1.91	1.89	
85b	4.90	2.79	0 24	1 36	1.91	2.21	0.02
87	4.80	4.30	0.24	2.25	1.72	2.18	0.02

The composition of the ash varied considerably with different samples. The contents of CaO and P_2O_5, however, were rather constant. It is well known that the ash of fresh milk varies in composition. It is natural, therefore, that the ash of powdered milk should do so. From the above analyses, it is very difficult to determine whether alkali has been added to the milk in manufacture. A list of ash analyses of partly or wholly skimmed-milk powders is given on the facing page.

A noteworthy point in these analyses is that there are indications in some cases that the milk was neutralized before manufacture. Nos. 18 and 4, especially, have very high alkalinity, about four times the usual. There are a few others that show a slight indication of having been neutralized. This practice cannot be too positively condemned.

The changes in milk constituents during the manufacture of powdered milk have been studied. The samples used for this purpose were prepared by the Merrell-Soule spray process. Every step was controlled; the temperature to which the milk was subjected prior to condensing, the vacuum, the steam pressure applied to the coils, and the temperature of the pan for condensing the milk prior to spraying were all recorded. The temperature of the drying chamber and the pressure applied to the milk for spraying were also recorded. Samples of the original milk, of the condensed milk, and of the finished powders were analyzed to see where the changes occurred and how. The results of the analyses are given in the next table.

Analyses of Milk, Condensed Milk and Milk Powders from Same Source

	Original Milk	Condensed Milk	Powdered Milk
Total dry matter	11.46	25.90	98.47
Water	88.54	74.10	1.53
Acid-coagulable protein	2 08	4.89	17.91
Heat-coagulable protein	0 23	0.67	2.41
Soluble protein	0.60	0.71	4.29
Total protein	2 90	6.26	24.62
Fat	3 12	6.67	25.85
Lactose	4.77	11.89	42.42
Ash	0.68	1.47	5.59

It is very hard to judge, simply by glancing at the analyses on the previous page what changes have occurred in the milk constituents during the process of manufacture. Therefore, the figures have been calculated on the basis of total dry matter.

PERCENTAGE COMPOSITION OF MILK, CONDENSED MILK AND MILK POWDERS, CALCULATED ON BASIS OF TOTAL DRY MATTER

	Original Milk	Condensed Milk	Powdered Milk
Acid-coagulable protein	18.15	18.86	18.19
Heat-coagulable protein	2.42	2.57	2.45
Soluble protein	5.20	2.76	4.36
Total protein...............	25.77	24.19	25.00
Fat.....................	27.17	25.76	26.25
Lactose....................	41.14	44.38	43.07
Ash....................	5.92	5.67	5.68

These figures show little change in acid- and heat-coagulable proteins, casein, and albumin, but a somewhat greater change in soluble protein. Fat was lost, and there was a slight reduction in ash. These losses caused an increase in lactose content. The loss of ash may be accounted for by partial precipitation, but the other losses are very difficult to account for. On the whole, however, it may be said that no material changes occur in milk constituents on drying by this particular spray process. It is very noteworthy that there was no change in heat-coagulable protein. Many people have supposed that powdered milk made by the spray method was subjected to a high temperature for a long period, causing a material change in the milk constituents. It has been proved that, with careful manipulation in the drying operation, the constituents of fresh milk can be almost exactly duplicated in powdered milk by the Merrell-Soule process. This is true not only of the general constituents of milk, but also of its enzyme content and other properties.

In a survey of the powdered milk on the Japanese market, it was found that in most cases heat-coagulable protein, or albumin, had been lost, showing that high heat had been applied to the milk in the course of manufacture. The application of high heat is also proved by the absence of enzymes in albumin-free powders.

ANALYSES OF PROTEINS OF MILK POWDERS COLLECTED ON MARKET

Sample No.	Acid-coagulable	Heat-coagulable	Soluble	Total
1	19.02	2 62	2.50	24.16
2	17.91	2 41	1.29	21.61
3	20 00	2.90	1.59	24.49
4	9 87	. . .	0 76	10.63
5	16 92	2 27	0 81	20 05
6	20 10	Trace	0 98	21.08
7	26 80	Trace	1 38	28.18
8	18 49	Trace	1 25	19.74
9	17 86	.	1 74	19.61
10	21 70	Trace	0 49	22 20
11	10 81	. . .	1 29	12 10
12	11.12	. . . .	0.94	12.06
13	23 94	Trace	5.18	29.12

Of thirteen different samples of powdered milk, four contained the normal amount of heat-coagulable protein. The others contained only a trace or none at all. Nos. 1, 2, and 3, which contained the most heat-coagulable protein, were manufactured either by the Merrell-Soule Company or by some company using the same process. No. 5, which also contained a nearly normal amount of heat-coagulable protein, was made by a drum process. Besides the three samples mentioned, Nos. 4, 7, and 8 were also made by a spray method. Nos. 6, 9, and 10, in addition to No. 5 which was already mentioned, were made by a drum method. The remaining samples, Nos. 11. 12, and 13, were all made by a dough method. No. 4 was also made by the Merrell-Soule drier, as were Nos. 1, 2, and 3; but the milk for drying was subjected to a very high preheating prior to condensing, as in the manufacture of ordinary condensed milk.

PROPERTIES OF FAT IN POWDERED MILK

The adulteration of milk fat is prohibited in most countries, and is therefore not to be expected in powdered milk. A certain brand of powdered milk was at one time suspected of containing added vegetable fat. Samples of this brand were examined for some of the constants of fat, and all of them were found to be

within the limits of normal variation. The final test for phytosterol was negative, proving the absence of vegetable fat in the suspected powdered milk.

Physical and Chemical Properties of Fat of Powdered Milk

	Sample Suspected	Normal Sample
Refractive index at 40° C.	1 4570	1.4580
Solidifying point	25° C.	20° C.
Melting point	32.5° C.	31° C.
Soluble volatile acid, per cent	5.47	5.99
Insoluble volatile acid, per cent	0.53	0.62
$\frac{\text{Insoluble volatile acid}}{\text{Soluble volatile acid}} \times 100$	9 69	10.35
Phytosterol test	Negative	Negative

The ratio of insoluble volatile acid to soluble volatile acid is a good indication for determining the adulteration of milk fat with vegetable fat. In the case cited above, the examination showed that this ratio was quite normal. The phytosterol test, which is the final criterion of such adulteration, was also negative. Therefore, the suspected sample was a perfectly wholesome product as far as the purity of the milk fat was concerned.

Dobbie again reported examinations of the fat of whole-milk and impoverished-milk powders, made at the Government Laboratory with the samples previously referred to. The examinations were made for soluble and insoluble volatile acids and for Zeiss number at 40° C.

Some Constants of Fat of Powdered Milk, Reported by Dobbie

Sample Number	Volatile Acids: Soluble or Reichert-Wollny Number	Volatile Acids: Insoluble	Zeiss Number at 40° C.
6	26.1	1.8	45.2
11	30.7	2 6	43.6
17	26.3	1.8	43.8
34	32.5	3.2	42.7
36	28.8	2.2	43.0
37	32.1	3.4	42.3
39	30 3	2.7	41.8
40	25.0	1.7	44.4
41	30.7	2.0	42.1
42	30.7	2.1	42.0
43	30.9	2.7	41.5
50	33.2	3 5	41.3
51	27.4	2 2	41.9
53	31.0	2 9	41.8
54	26.8	1.6	44.7
56	30 6	2.8	43.5
58	30 9	2.9	43 2
60	29.3	2 9	44.4
61	27 9	2 2	44.2
62	26.8	2.1	43 9
63	29.5	2 1	43.9
64	30 9	2 9	44.8
65	26.1	2 0	45 3
69	29 1	1.7	44.2
71	30.0	2.1	42 8
72	29 5	1.9	43.1
73	29.0	1 8	43 8
74	28.7	2 3	42.8
75	28 3	2.1	42.5
76	29 8	1.6	42 4
78	29 4	1.7	43.7
79	28.6	2.4	43.6
80	20 0	1.4	44.4

While no certain conclusion can be drawn from the above figures, they appear to indicate that there was no adulteration of fat in any of the samples examined.

Enzymes

It is believed by many persons that the enzymes present in the fresh milk are destroyed during the process of manufacture and are not found in powdered milk. This is not always true. Many tests for enzymes in powdered milk have been conducted, and studies have been made of the effect of the manufacturing process upon them. In powdered milk manufactured either by the dough or the drum process, enzymes are usually absent; while powdered milk manufactured by the spray process often shows their presence. With precaution in heating milk before condensation prior to spraying, the enzymic activities may be retained. If the product is kept for a long time, especially in the air, these activities are gradually weakened.

Lane-Claypon [5] has indicated the fallacy of attaching too much importance to the presence of enzymes in powdered milk. He found that when a young animal was fed with the milk of a different species, it was of little or no consequence whether or not the enzymes had been affected by the heating of the milk. This may be true, and the presence of enzymes may be of no importance from the standpoint of nutrition; in fact, in some cases, they are rather troublesome. Nevertheless, the presence of enzymes in powdered milk is a good indication of the use of a low temperature in the manufacturing process. Since vitamin C is very susceptible to heat, the retention of the antiscorbutic potency of powdered milk may be accomplished by avoiding the use of a high temperature. The destruction temperature of vitamin C coincides very nearly with that of enzymes.

Properties of Powdered Milk on Reconstitution

Some experiments on the properties of reconstituted milk gave the results shown in the following table.

The first two show the Storch reaction, indicating that the enzymes are uninjured, and also respond to rennet. These tests indicate the retention of the properties of fresh milk. These brands are made by a spray process. The other three are drum-process powders, one being made with a Buflovak machine. The

[5] Jenet E. Lane-Claypon, Rept. to Local Govt. Board, New Series No. 76, 1913.

negative tests by the Storch reaction and with rennet show the effect of heat. In the case of the vacuum-drum product, even the very short time of contact with the hot drum seems to have been sufficient to destroy the enzymes and render some of the soluble salts insoluble.

PROPERTIES OF POWDERED MILK ON RECONSTITUTION

Brand	Specific Gravity	Acidity	Freezing Point	Osmotic Pressure, Atmos.	Surface Tension c/d	Storch Reaction	Rennet Reaction
Klim	1.0310	0.164	−0.565	6.67	53.32	+	+
Kintaro. . . .	1.0345	0.175	−0 610	7.20	49.88	+	+
Glaxo.	1.0360	0.187	−0.675	7.97	46.44	−	−
Lactogen. . .	1.0320	0.105	−0 580	6 92	52 03	−	−
Morinaga. . .	1.0350	0.070	−0 590	6.96	50.31	−	−

VITAMINS IN POWDERED MILK

Since the discovery of vitamins, the problems they present have become very important in the discussion of food materials, especially in the case of infant foods. As powdered milk is used largely for infant feeding, it has been subjected to considerable research in regard to its vitamin content.

Robert James Blackham, in his report to the World's Dairy Congress of 1923, emphasized the merits of powdered milk for infant feeding, from the standpoints of vitamin content and digestibility. Vitamins A and B are not destroyed by the temperatures usually employed in the manufacture of powdered milk. Vitamin A is weakened or entirely destroyed by oxidation, which may occur in powdered milk if it is kept in the air. Vitamin C is very susceptible to heat and is very likely to be destroyed by this agency in the course of manufacture. It is also subject to destruction by oxidation. Therefore, vitamin C may be destroyed on keeping the product in air, even though it has been successfully retained in manufacture. Vitamin C is entirely destroyed by double heating; and prolonged heating weakens its activity to a degree depending on the temperature employed and

the length of time that the milk is exposed to this temperature during the process of manufacture. An instantaneous boiling or a momentary exposure to a temperature near the boiling point is said to have little influence on the activity of vitamin C.

There is considerable difference of opinion among investigators regarding the presence of vitamins in powdered milk. Cornelia Kennedy,[6] in her report to the World's Dairy Congress of 1923, quoted Osborn and Mendel, whose investigations had proved the presence of vitamins A and B in powdered milk.

Vitamin B.—According to Dr. Kennedy, vitamin B is probably always present in powdered milk, but the amount varies. McCollum and Davis [7] reported that normal growth in rats was obtained by the addition of only 2 per cent of powdered milk to a ration complete in all nutrients except vitamin B. Osborn and Mendel [8] reported that when powdered milk was used as the sole source of vitamin B, it was necessary to add at least 24 per cent of powdered milk to a ration supplied with sufficient protein, salts, butter fat, and starch, in order to insure the rapid growth of rats. This is more than ten times the amount reported by McCollum and his associate. Sherman [9] reported a normal growth of rats on a ration containing 7.5 per cent, or 0.8 gram, of skimmed-milk powder per day.

The results so far reported vary considerably in regard to the amount of powdered milk to be supplied to growing rats as a source of vitamin B. The cause of these variations is an open question. It is difficult to decide whether or not the vitamin-B content really varies in different samples of powdered milk, and whether the variation is due to the environment and individuality of experimental animals or to the methods employed by different investigators. It is very probable that vitamin B varies in different powders, as its presence in powdered milk is undoubtedly governed by the amount present in the original milk. It may also vary with the methods of manufacture and the age of the powders.

Sherman[10] and his associates found that, when an equivalent

[6] World's Dairy Congr., 1923, Proc., p. 198.

[7] McCollum, E. V., and Davis, M., Jour. Biol. Chem., 1915, 20, 641.

[8] Osborn, T. B., and Mendel, L. B., Jour. Biol. Chem., 1918, 34, 537.

[9] Sherman, H. C., and Smith, S. L., The Vitamins, 1922.

[10] Sherman, H. C., Rouse, M. E., Allen, B., and Wood, E., Jour. Biol. Chem., 1921, 46, 503.

amount of milk solids, in addition to bread, was given to each group of experimental animals, they made equally rapid growth throughout the experimental period, although one group received pasteurized milk, another reconstituted milk made from powdered milk, and the third the powdered milk in its dry form. These workers concluded that vitamin B is not destroyed by drying milk. This conclusion may be justified; but the pasteurized milk used in the experiment was not the original milk from which the powdered milk employed in the same experiment was manufactured. Therefore, no certain conclusion can be drawn from the result. Nevertheless, it is true that the effect of drying on vitamin B is very slight. Johnson[11] made a similar investigation; comparing reconstituted milk, made from powdered milk manufactured by a spray process, with fresh and pasteurized milk, he reached a similar conclusion. With Hooper,[12] he also proved that drying has no effect on the antineuritic vitamin of skimmed milk. These investigators state that, to prevent polyneuritis in pigeons, it is necessary to give from 6 to 7 grams of powdered skimmed milk daily. This is equivalent to about 75 cc. of fresh milk and is less than the minimum protective amount of fresh milk considered by Gibson and Concepcion.[13]

Vitamin A.—While considerable work has been done on vitamin B of powdered milk, comparatively little study has been made of vitamin A. Since vitamin A is associated with fat, its presence in powdered milk must naturally be dependent on the amount of fat contained therein. Therefore, it is natural to suppose that vitamin A must be less abundant in the skimmed-milk product than in whole-milk powder. Sherman [14] and his associates, however, report that the skimmed milk product contains a considerable amount of vitamin A—half as much as the whole-milk powder. If this is true, the vitamin A of the powdered whole milk must have been destroyed either in course of manufacture or on keeping, since an increase of vitamin A by drying skimmed milk is hardly possible. Though vitamin A is not so susceptible to the degree of

[11] Johnson, J. M., Public Health Rept., Vol. 36, No. 34, 1921, 2044.

[12] Johnson, J. M., and Hooper, C. W., Public Health Rept., Vol. 36, No. 34, 1921, 2037.

[13] Gibson, R. B., and Concepcion, I., Philippine Jour. Sci., 1916, 11, B. 119.

[14] Sherman, H. C., MacNeod, F. L., and Kramer, M. M., Proc. Soc. Expt. Biol. Med., 1920, 18, 41.

heat generally employed in the manufacture of powdered milk, it is easily destroyed by oxidation. Upon drying milk, the fat is exposed to the air; and there are chances for oxidation during the process of manufacture, especially when a high temperature is applied to the milk. Prolonged exposure of powders to the air also gives opportunity for slow oxidation. In fact, when powdered whole milk is kept exposed to the air, there is a pronounced change in the flavor, apparently resulting from the oxidation of milk fat. If vitamin A is destroyed by prolonged exposure to the air, the period of keeping, the method of packing, and the character of the powder must influence the keeping quality of powdered milk. The comparatively high vitamin-A content of powdered skimmed milk may be accounted for by the fact that the fat remaining in skimmed milk is very small in quantity as well as in size of fat globules, and that, upon drying, most of the fat globules must be enclosed in a dried mass of other milk solids, thus escaping exposure to the air.

Winfield[15] gave experimental animals powdered milk, not dissolved but left in the dry form and in the pasty form. In either case, water was separately supplied *ad libitum*. The animals used for the experiment were young suckling rats, the test being started somewhat earlier than they would normally leave the mothers. More than forty rats were used in the experiment. In every case except a few—five animals in all, which died early from accidental causes—the rats remained in good health upon this dietary. Certain animals, ten in all, remained upon this exclusive diet for periods extending to sixteen months and more. As the length of life of the white rat is approximately three years, these animals received no food except powdered milk for nearly half their lifetime. It is said that, to all appearances, their general health remained perfect. The animals made normal growth for several weeks, and often for as much as three months, on a diet of powdered milk alone. At some period, varying with the age at which the powdered milk first became the sole food, but commonly when the animal had reached from one-half to two-thirds of its full adult weight, the rate of growth fell off from the normal and was only renewed when a mixed diet took the place of the dried milk. This shows that powdered milk is deficient in pro-

[15] Winfield, G., Rept. to Local Govt. Board, Food Rept. No. 24, 1920, 139.

moting the growth of the rat after a certain stage of growth is reached. This is not peculiar to powdered milk, but is a defect of milk in general, as the addition of fresh milk alone at this stage produced no acceleration of growth. This nutritive fault, Winfield declares, is characteristic of milk in all forms, not to the dried preparation alone.

Mattil and Conklin[16] report a similar case. They found that the growth of rats was retarded, after fifty to a hundred days of continued feeding, on a diet consisting entirely of either powdered milk or fresh milk. This retardation was not due to a deficiency of vitamin A, as there was no stimulation of growth upon the addition of 10 per cent milk fat to the diet. Neither was it due to a deficiency of vitamin B, because, by the addition to the diet of lard and starch, both free from vitamin B, a satisfactory growth was maintained.

Kennedy[17] made an investigation of the effect of methods of manufacturing powdered milk on vitamin content. The processes studied were the spray and drum-drying methods. In the spraying method, the fresh milk was first condensed in a vacuum pan to a certain thickness, at a temperature ranging from 50° to 55° C. It was then sprayed under pressure into a hot chamber, the temperature of which ranged from 80° to 85° C. In the drum-drying method, a thin film of milk was run directly on to the surface of a steam-heated revolving drum and thus dried in a few seconds. The dried film was scraped off by a scraper. It was stated that the latter product was subjected to high temperature and oxidation to a lesser degree than the sprayed powder, and that consequently the vitamins were better protected in the powdered milk made by the drum method.

The samples of powdered milk used for this investigation differed not only in method of manufacture but also in fat content. The sprayed product was made from whole milk, and the drum-dried product from partly skimmed milk. These powders were dissolved in water and the freezing point of each was determined, to insure that the reconstituted milk had properties similar to those of ordinary fresh milk. The powders were then fed to white rats. The animals received an ample supply of all the nutrients

[16] Mattil, H. A., and Conklin, R. E., Jour. Biol. Chem., 1920, 44, 137.
[17] Kennedy, Cornelia, Proc., World's Dairy Congress, 1923, Vol. I, 201.

except vitamins A and B. To supply these vitamins; 10 cc. of reconstituted milk were given to each animal, as this amount is said to be the minimum requirement of fresh milk in such cases. The experiment was conducted throughout the year, to eliminate the seasonal factors influencing the vitamin content of milk. The result did not show any noticeable difference in the products of the two methods. It is stated, however, that, as a source of vitamin A, the drum-dried product showed a tendency to produce better growth than the spray-dried milk. As sources of vitamin B, there was no difference whatsoever between the two.

Vitamin C.—Vitamins A and B are present in powdered milk and are not much affected by the different processes of manufacture. This is not true of vitamin C, however. There is considerable difference of opinion about the presence of this vitamin in powdered milk. Vitamin C is the most unstable of all vitamins. It is very susceptible to heat and to oxidation. To insure antiscorbutic potency in powdered milk, it is very essential to have it in the original milk. It is also necessary to dry the milk rapidly and to protect it from oxidation. The antiscorbutic property of powdered milk depends not only on the temperature to which the milk is subjected during the process of manufacture, but also on the duration of exposure to heat and oxidation. It is also governed by the content of vitamin C in the original milk. On these suppositions, Kennedy states that in the sprayed product, which is exposed to hot air for a long period, vitamin C is destroyed for the most part, if not entirely; while powdered milk made by the drum method, being dried almost instantaneously and less exposed to air, retains a greater portion of vitamin C.

Hart[18] and his associates found a considerable difference in the antiscorbutic property of samples of powdered milk, and declare that this difference is due not only to variations in the original milk, but also to the methods of manufacture. They pointed out that in the spray-dried product vitamin C was destroyed to a greater degree than in drum-dried milk.

According to Hess,[19] by feeding daily, to guinea pigs, 80 cc. of reconstituted milk, from powdered milk made by the Just-Hatmaker process (a drum method), scurvy was prevented. They

[18] Hart, E. B., Steenbock, H., and Ellis, N. R., Jour. Biol. Chem., 1921, 46, 309.
[19] Hess, A. F., and Unger, L. J., Jour. Biol. Chem., 1919, 38, 293.

make no statement regarding its relation to the fresh milk. According to other investigators, to show the antiscorbutic potency of fresh milk, 30 to 150 cc.—a wide range—are required. Therefore, in order to reach any definite conclusion as to the antiscorbutic property of powdered milk made by different methods, the relation between the antiscorbutic potencies of milk before and after drying must be studied. Hess states, in his "Scurvy, Past and Present," that powdered milk manufactured by the Just-Hatmaker process retains its power of preventing scurvy in infants for at least six months after manufacture.

Contrary to the statements made by the foregoing authors, Barnes and Hume[20] reported that guinea pigs and monkeys could not be protected from scurvy when fed with drum-dried milk in amounts equivalent to the quantity of fresh milk which protected animals from scurvy. Suzuki[21] reported Uejima's work on vitamin C in milk and milk products. Fresh milk contained vitamin C, but the market milk of Tokyo did not contain it. At the time of the experiment, no powdered milk that showed the presence of vitamin C was found on the Tokyo market, while fresh condensed milk contained a very slight amount.

The question of the presence of vitamin C in powdered milk cannot be answered with certainty. The method of manufacture undoubtedly has a great influence; but it is too early at present to conclude that drum processes always retain the activity of vitamin C and spray processes destroy it. There are many drum processes that have an ill effect on vitamin C, and there are some spray processes that show good results. Even with the same machine, variations in the manner of handling the milk may have some influence. The mode of handling the dried product after manufacture and the method of packing also affect the vitamin-C content.

Jephcott and Bacharack[22] compared spray-dried milk with drum-dried milk made from summer, winter, and neutralized milk. They report that summer and winter milk products were practically equal in antiscorbutic value. The neutralized milk prod-

uct was a little inferior, and the spray-dried product was decidedly deficient. They point out that scurvy was prevented in guinea pigs by feeding 26 cc. per day of reconstituted milk made from drum-dried milk to every 100 grams live weight.

Cavanaugh[23] and his associates studied the effect of a spray process on vitamin C. They used guinea pigs for experimental animals. In addition to a basal ration, raw milk or spray-process powdered milk was given to the animals in various amounts. The raw and powdered milks used for the experiment were daily supplied by the Merrell-Soule powdered milk factory at Perry, N. Y., and represented the mixed milk of 175 farmers, obtained from 1276 cows. The raw milk was cooled and sent in sterilized bottles. The powdered milk was manufactured by pasteurizing raw milk at a temperature at which vitamin C is intact. The experiment was carried out in summer as well as in winter. The results were kept separately. The investigators report that vitamin C can be retained in powdered milk manufactured by the spray process, and that its potency does not differ much from that of the original raw milk. They also report on the effect of keeping. The results, up to date, justify the statement that the antiscorbutic property of the sprayed powders will be retained for several months.

In spite of many conflicting reports of various investigators, it is safe to say that, with any method of manufacture, vitamins may be retained by careful manipulation of the drying machine, careful control of the heat applied to the milk during manufacture, and proper packing of the powders.

BACTERIA IN POWDERED MILK

The hygienic and general qualities of a food are often determined by its bacterial content. The quality of market milk is generally judged by the number of bacteria contained in it. Harding, however, is emphasizing the importance of the kind of bacteria, as distinguished from their number, in judging milk and milk products. The number of bacteria per unit quantity of milk may be very important in judging the general quality of fresh milk,

[23] Cavanaugh, G. W., Dutcher, R. A., and Hull, J. S., Am. Jour. Dis. Child., 1923, Vol. 25, 498.

but it means very little with other milk products. Fresh milk usually contains comparatively few bacteria, the number increasing rapidly as the milk gets older. With other milk products, the reverse is true in most cases. Fresh butter, condensed milk, and powdered milk usually contain a comparatively large number of bacteria, and with age the bacterial count gradually decreases. Therefore, as Harding says, it is the kind of bacteria, and not merely their number, that is important.

Since powdered milk was not of great importance as a commercial article until recently, there has been but little bacterial study of this product. Formerly, it was taken for granted that powdered milk was sterile when it came out of the drier. Coutts[24] reviewed the literature on this subject. Grosso, in 1907, counted, on a plate culture, the number of bacteria in powdered milk made by Hatmaker, and found 4000 to 5400 bacteria per gram of powder. Among the bacteria recognized were *Bacillus brevis*, *B. subtilis*, *B. amarificans*, *B. subbutyricus*, *Micrococcus varians*, *M. corrugatus*, and *M. eburneus*. It was said that no pathogenic bacteria were discovered.

Kossovicz investigated the sterility of powdered milk prepared by the Hatmaker drum process. He found that the product was not sterile, but contained 45 to 80 bacteria, when a sample was taken immediately after passing over the drying cylinders. The kind of bacteria found were *B. mesentericus fuscus*, *B. mesentericus ruber*, *B. subtilis* and a butyric acid bacillus. Considerable contamination had already occurred in the collecting boxes, the number of bacteria being increased to 750 to 1250, Molds were also found. On keeping for two months, the bacterial count decreased to about 450. On packing in tin cans, soldered, the bacterial count increased to 1850 to 2460. The varieties found included *B. subtilis*, *B. mesentericus fuscus*, *Sarcina alba*, *Sarcina lutea*, *streptococci*, *Aspergillus glaucus*, and *Penicillium glaucum*.

Tubercle Bacilli.—The fate of tubercle bacilli in powdered milk is the most important question that arises in a bacteriological study of this product. Hoffman investigated a milk dried over cylinders, which had a surface temperature of 110° C. and revolved at seven revolutions per minute, giving about five seconds' exposure of the milk film to the heat. The milk he used was

[24] Coutts, F. J. H., Rept. to Local Govt. Board, Food Rept. No. 24, 43.

mixed with a culture of virulent tubercle bacilli in such quantity that the sediment, when centrifuged, showed under the microscope 3 to 5 tubercle bacilli in the field. Some guinea pigs were inoculated with the sediment of reconstituted milk made from the dried milk; others were fed with the dried milk. In a few weeks the control animals showed swelling of the inguinal glands. One died forty-eight days after inoculation, and another was killed fifty days after inoculation. Both showed generalized tuberculosis. Those inoculated with the infected dried milk were free from tuberculosis. This shows that by the drum process, at least according to Hoffman's study, tubercle bacilli are destroyed.

Guedras, on the other hand, is very cautious in his view of the problem and suggests the importance of selecting tubercle-free animals for supplying milk for manufacture. From his experiment in regard to casein, he states that the tubercle bacilli may retain their virulence after a considerable amount of commercial treatment. He took tuberculous milk, and, after centrifuging it, precipitated casein and dried it under commercial conditions. Guinea pigs inoculated with this casein succumbed to tuberculosis about the thirty-seventh or thirty-eighth day. He states, therefore, the tubercle bacilli can resist such manipulations as precipitation by acid, redissolving in alkali, further precipitation, drying, etc. In this case, however, the drying temperature was low, which may account for the retention of the virulence of the tubercle bacilli.

The thermal death point of tubercle bacilli is very important. Unfortunately, the evidence set forth by many investigators is very conflicting. It is generally accepted that tubercle bacilli lose their virulence for guinea pigs when the milk is pasteurized at 60° C. for twenty minutes, or when it is subjected to flashing at 80° C. Delepine, however, refers to experiments he made in 1899, which showed that cream infected with human tubercle bacilli was not invariably sterilized even after exposure for fifteen minutes at a temperature of 85° C. He also experimented with tubercle bacilli from a cow, drying the milk by the drum process. He found that some tubercle bacilli had survived and were still capable of producing progressive tuberculosis in guinea pigs inoculated subcutaneously with milk containing them.

Hunwicke and Jephcott[25] made similar investigations. Their results are not in concordance with Delepine's. They took fresh milk, not sterilized, and divided it into two portions, one of which was inoculated with a strain of human tuberculosis, and the other with a strain of bovine tuberculosis. Fifty cubic centimeters of milk were centrifuged, and the sediments mixed with 20 cc. of sterile water. Five cubic centimeters of this mixture were then injected into guinea pigs. Two guinea pigs were inoculated with milk containing bovine tubercle bacilli, and the other two with milk containing human tubercle bacilli.

The inoculated milk was dried on a drum drier. The dried powder was reconstituted with sterile water, and two guinea pigs were inoculated with the sediments from the sample which had contained human tubercle bacilli before drying, and two with that which had contained bovine tubercle bacilli.

The control animals showed that both samples of milk were heavily infected with *B. tuberculosis* of human and bovine origins, respectively. The other four animals which had been inoculated with the reconstituted milk showed no lesions, and all were well-nourished, healthy animals. Therefore, Hunwicke and Jephcott declare that the process of drying milk either killed the bacilli or rendered them non-virulent. They explain the difference between Delepine's results and theirs in the following manner: It is quite possible that a difference in the conditions of steam pressure and speed of rollers (drum) accounts for the different results. If this is so, powdered milk manufactured by the drum method cannot be said to be always safeguarded against tubercle bacilli, unless the steam pressure applied to the drum and its speed of revolution are carefully controlled.

Other Obnoxious Bacteria.—Klein reported that powdered milk manufactured by the Ekenberg process was free from staphylococci, streptococci, bacilli of the diphtheria group, and those of the *coli communis* group. The experiments were made with fresh milk infected with *B. coli communis*, *B. typhosus*, diphtheria bacilli, and a mixture of *Staphylococcus aureus* and *B. prodigiosus*. The milk was then dried by the Ekenberg process. On examination of the dried product, it was found that none of the bacteria with which the fresh milk had been infected were present.

[25] Hunwicke, R. F., and Jephcott, H., Jour. Dairy Sci., Vol. VIII, No. 3, 214.

The virulence of tubercle bacilli was also studied with the Ekenberg process, and it was found that guinea pigs inoculated with an amount equal to $\frac{1}{7}$ gram of the powder showed no trace of tuberculosis after twenty-one days, while the control animal showed definite tuberculosis.

General Survey of Bacteria in Powdered Milk.—Coutts[26] reports the results of bacteriological investigations on 42 samples of powdered milk submitted to the Lister Institute for examination. The highest figures for aërobes growing at blood temperature was 11,900 per cubic centimeter in dissolved powdered milk, 1 gram being dissolved in sterile water and made up to 10 cc. The highest number for aërobes growing at room temperature (22° C.) was 86,400 per cubic centimeter. These figures are for whole-milk products, and even the worst ones are satisfactory, so far as the number of bacteria is concerned, when compared with ordinary market milk. There were many samples very low in bacterial count. The majority showed less than 1000 bacteria per cubic centimeter. Fresh milk produced under the most aseptic conditions usually shows more than 1000 bacteria per cubic centimeter. The smallest number of aërobes growing at 22° C. was 100. The majority of samples showed less than 2000 per cubic centimeter. As regards anaërobes, the numbers for whole-milk powders were all very low.

With samples of completely or partly skimmed milk powders, the number of aërobes varied much more, and in some cases they were higher than 500,000 per cubic centimeter both at 37° C. and at 22° C. There were also samples showing a great number of anaërobes, sometimes as many as 56,960, the two kinds of bacteria totaling over 800,000 per cubic centimeter. On the whole, the number of bacteria in partly skimmed or skimmed-milk powders is less than 5000 per cubic centimeter, which is very satisfactory.

According to the same study, the *B. coli* type of bacteria was absent from all samples, which is very satisfactory for a milk substitute such as powdered milk, from a hygienic standpoint. Streptococci were more frequently in evidence, and also *B. enteritidis sporogenes.* The presence of the latter is explained by its high resistance to heat. The presence of low-heat-resisting strep-

[26] Coutts, F. J. H., Rept. to Local Govt. Board, Food Rept., No. 24, 1920.

tococci in powdered milk must be accounted for by recontamination in the processes of powdering and packing after drying. Tubercle bacilli were not detected, and their absence is greatly to the credit of powdered milk.

Delepine[27] studied the influence of the drum and spray methods of drying milk on bacterial counts immediately after manufacture. He found that an enormous reduction in the number of bacteria occurred in the process of drying milk. He also found that a large proportion of the bacteria in commercial dried milk were the result of recontamination after drying. With the drum process, 588,000 per cubic centimeter, the number of bacteria present in the original milk, were reduced to 300 per gram of powder as it fell from the hot drum. This number immediately increased to 14,600 per gram of powder as it fell from the powdering mill, still warm. With the spray method, the freshly dried milk did not show so low a bacterial count as with the drum process, but the reduction was also enormous. The original milk used for manufacturing powdered milk by the spray method contained as many as 14,120,000 bacteria per cubic centimeter, many more than the milk used in the drum method. This number was reduced to 15,200 per gram of powder as collected in the hot drying chamber, but it immediately increased to 154,000 per gram upon being sieved and packed.

The types of bacteria originally present in fresh milk do not seem to appear in powdered milk, except some types of spore-bearing bacilli and streptothrichae which appear in powdered milk made by both drum and spray methods. All other types of bacteria that are to be found in the powder seem to be the result of recontamination. Therefore, the number of bacteria is increased by recontamination immediately after manufacture. As already stated, this number is decreased again on keeping. This is an indication that the bacteria do not multiply in dried powder. Delepine also reports that a sample of dried milk, shortly after drying, showed 4900 bacteria per cubic centimeter of reconstituted milk, after being kept on an aërobic gelatin plate for seventy-two hours at 20° C. After being kept for one hundred and twelve days, the same sample of dried milk had fallen in number of bacteria to 4180 per cubic centimeter. On aërobic litmus agar

[27] Delepine, Rept. to Local Govt. Board, Food Rept., No. 24.

plates (seventy-two hours at 37° C.), the same milk gave, shortly after drying, 800 organisms per cubic centimeter of reconstituted milk. After it had been kept in the dry form for one hundred and twelve days, the number decreased to 500 and 600 per cubic centimeter.

Supplee and Ashbaugh[28] quote Down's investigation of the bacterial flora of powdered milk. He found a wide variation in number of bacteria per gram of powdered milk made by different methods, as well as in individual samples from the same method. The average count of ten samples dried by the drum method, in which the milk was previously condensed, was 49,500 per gram, with a maximum count of 626,000 and a minimum of 16,900; all counts except three were below 50,000. The average of ten samples dried by the spray method, in which the milk was previously pasteurized and condensed, was 178,000 per gram, with a maximum of 595,000 and a minimum of 15,600; four counts were below 50,000. The average of nine samples of the spray method, in which the milk was not previously condensed, was 2,269,000 per gram, with a maximum count of 3,500,000 and a minimum count of 1,500,000. Supplee and his associate made a study of the bacterial flora of powdered milk made by the Just process. In conclusion, they say that any bacterial count over 1000 per gram, in powdered milk made by the Just process, may be assumed, in a majority of cases, to be due to recontamination after the powder has left the drying cylinders; that the bacterial content of the dried milk solids, immediately after drying and before being subjected to recontamination, does not seem to be affected by the number of bacteria in the liquid milk prior to drying, provided such milk contains a normal flora; that the bacteria in powdered milk die off rapidly during storage, reaching a point of approximate constancy, in normal powders made by the process under investigation, after two to four months; and that the presence of a large number of bacteria in desiccated milk does not produce any detectable effect upon the keeping quality in the presence of moisture concentrations which would admit the powder as a commercial article.

Hunwicke and Jephcott's work on the virulence of tubercle bacilli in powdered milk has already been referred to. In con-

[28] Supplee, G. C., and Ashbaugh, V. J., Jour. Dairy Sci., Vol. V, 217.

nection with that study, they also made a general survey of the bacterial flora of powdered milk, and reported, in conclusion, that the roller process of milk drying is capable of completely destroying non-spore-bearing bacteria; that the spores of spore-bearing bacilli are not destroyed in all cases by the process; and that the number of survivors of this type of organism is probably dependent on the extent to which sporulation has occurred among them.

In connection with the experiments conducted at Sapporo on methods of packing powdered milk, a study was made of the effect of packing methods on bacterial content. Samples of powdered milk were packed in tin cans and in bottles of light and brown colors. Six different methods of packing were studied: two samples were packed in vacuum, one in a light bottle and the other in a brown bottle; one with hydrogen gas, in a tin can; one with oxygen-free air, in a tin can; one with carbon dioxide gas, in a tin can; and one with air, in a tin can, just as is ordinarily done in packing powdered milk. The samples were kept in an incubator at 37° C. for three, six, and nine weeks. The bacterial counts were made first with freshly made sprayed powder on the next day after manufacture. Incubated samples were taken for bacterial count at the end of three, six, and nine weeks. The results of the counts are summarized in the table on p. 292.

The results are not entirely consistent, but it is notable that the number of bacteria decreases very rapidly on incubation at 37° C. The decrease in number of bacteria was very marked in the samples put up in packages from which oxygen was excluded.

The above experiments show that bacterial life in powdered milk is much shortened when the product is packed in the absence of oxygen. The decrease was greatest in light vacuum-packed samples. Other vacuum packings were similar in effect. While it is not probable that the bacteria in powdered milk of the usual moisture content are responsible for its deterioration, and while a smaller number of bacteria is not an indication of freshness, the presence of these organisms in powdered milk cannot be overlooked. Any way of destroying them without ill effect upon the powdered milk must be an improvement. Vacuum packing is very efficient for destroying the bacteria present in powdered milk soon after manufacture. Packing in inert gases is another way of arriving at this goal.

THE EFFECT OF METHODS OF PACKING ON BACTERIAL COUNTS OF POWDERED MILK

Sample No. 90725	Original Count	After Incubation for— 3 Weeks	6 Weeks	9 Weeks
Control, or air-packed	12,400	....	9700	4600
Vacuum-packed, light bottle	12,400	....	2500	1000
Vacuum-packed, brown bottle	12,400	....	2400	1300
Hydrogen-packed	12,400	....	3000	3500
Oxygen-free air-packed	12,400	....	5000	4100
CO_2-packed	12,400	....	2300	3900
Sample No. 91925				
Control, or air-packed	14,100	5000	8000	6200
Vacuum-packed, light bottle	14,100	7200	800	900
Vacuum-packed, brown bottle	14,100	4500	1000	1000
Hydrogen-packed	14,100	1700	2200	1600
Oxygen-free air-packed	14,100	1900	4800	1700
CO_2-packed	14,100	6900	3400	1300
Average				
Control, or air-packed	13,250	....	8850	5400
Vacuum-packed, light bottle	13,250	....	1650	950
Vacuum-packed, brown bottle	13,250	....	1700	1150
Hydrogen-packed	13,250	....	2600	2550
Oxygen-free air-packed	13,250	...	4900	2900
CO_2-packed	13,250	...	2850	2600

Electricity has been tried as a means of destroying bacterial life, with very little success. A sample of powdered milk made by a spray process was subjected to an electric charge of 50,000 to 80,000 volts in connection with a powder-collecting experiment. The effect of this extremely high voltage on the bacterial life of the powder was also determined. The results showed that even such a high voltage of electricity has no effect on bacterial life, at least for the short time of exposure in the experiment.

PHYSICAL AND CHEMICAL PROPERTIES OF POWDERED MILK

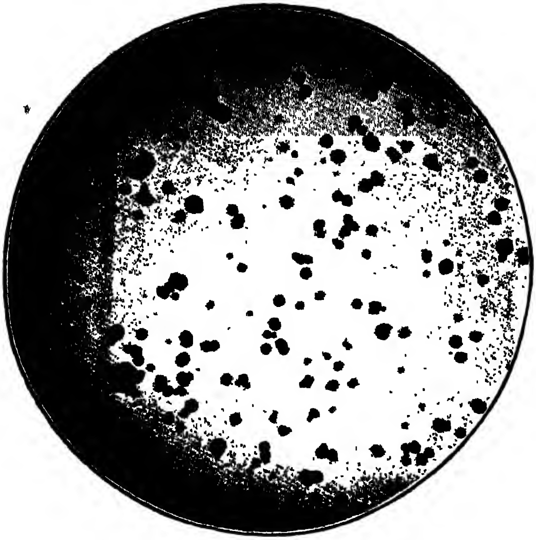
The powdered milk found on the market in tin cans varies in its appearance, according to brands, methods of manufacture, the properties of the original milk used for manufacture, and the age of the powder.

Color.—The color of powdered milk is usually a light cream. The physical condition of the powder has an influence on the

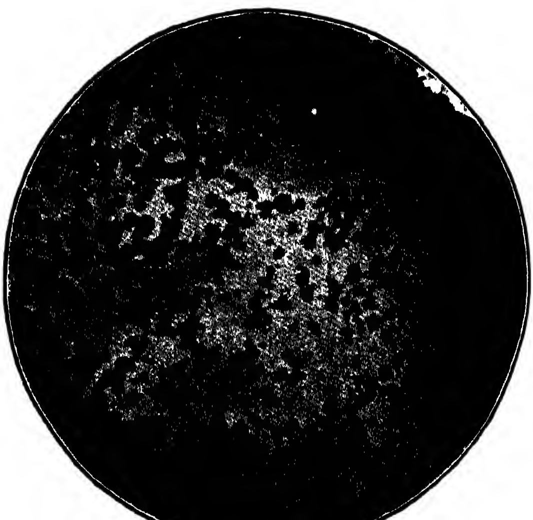
reflection of light, and consequently on the shade of color. Fine and uniform powders give very even and lighter shades. Often, a rich yellowish color is noticed. This is due to the use of highly colored fresh milk from cows on green pasture. The apparent color of powdered milk is not necessarily an indication of the richness of the fat content; in fact, the color is often misleading. Klim, a brand of powdered milk manufactured in the United States by a spray process, for instance, has a rather light color compared with some Australian and New Zealand products, such as the Glaxo and Lactogen brands, in spite of the fact that the first contains as much fat as the others, if not more. Klim is a fine powder, while the others are flaky powders.

Some powdered milk has a brown tinge. Normal powdered milk of good quality should not have such a color. If the original milk used for drying is heavily neutralized, the dried powders often have a brownish color even at the time of manufacture, but more often on keeping. Another cause for this coloring is a high temperature applied to milk in process of manufacture. On prolonged keeping, the color is deepened, the rapidity and the degree depending on the temperature of keeping and the moisture content of the powdered milk. The higher the temperature and moisture content, the more rapid and deeper the color change.

Powder Grains.—The forms of powder grains vary greatly, depending primarily on the process of manufacture. Powdered milk made by a spray process is usually in fine and comparatively uniform spherical grains of varying size. The smallest spheres measured were about 2.7 microns in diameter. The larger grains measured over 50 microns in diameter. The majority of grains of powdered milk measured about 30 microns. These grains are in general separate, but very small grains usually cling to larger grains. Often a number of grains stick together. When they are examined under a low-power microscope, they sometimes look like budding yeast cells. When a grain is suspended in alcohol to prevent it from dissolving, and is examined under the microscope, fat globules can be detected, embedded in the other milk solids and attached to the surface of the grain. The fat globules are not necessarily in the shape of spheres, especially those on the outer surface, but are often rather flattened. When 80 per cent alcohol is used for suspending the powder grain, the fat on the outer sur-



Milk Precondensed.



Milk not Precondensed.

FIG. 55.—SPRAY-PROCESS POWDER GRAINS.

There is not much difference in size, but those of the powder made from precondensed milk seem more solid.

face assumes a spherical shape and slowly detaches itself from the grain. When ether is added, the detaching fat globules rapidly run away from the grain and are dissolved in the ether. These phenomena can be seen under the microscope, and are very interesting. When, however, 80 per cent alcohol is used for suspending the powder grain, the cohesion of the fat is accentuated, giving the particles a tendency to form larger globules. To see the real size of the fat globules attached to the surface, it is better to fix the powder grain on a glass slide with absolute alcohol, stain it with eosin, and examine it in water. The powder thus treated is rendered insoluble in water, and the fat attached to the outer sur-

face of the grain appears in the form of very fine globules. Air cores are often found in the grains, the frequency and size of the air cores depending on the method of spraying. The grains of powdered milk made by the drum process are very irregular in shape and size. Under the low-power microscope, they look like crushed stone. The surface is very rough and folded. They are really flaky, the flakes having broken outlines. Therefore, this kind of powdered milk requires more space for a given amount. Because of their shape, it is difficult to measure the size of the flakes. The size of the flakes varies with the different brands of powdered milk. Some manufacturers grind the dried

Glaxo.

Lactogen.

Fig. 56.—Drum-process Powder Grains.

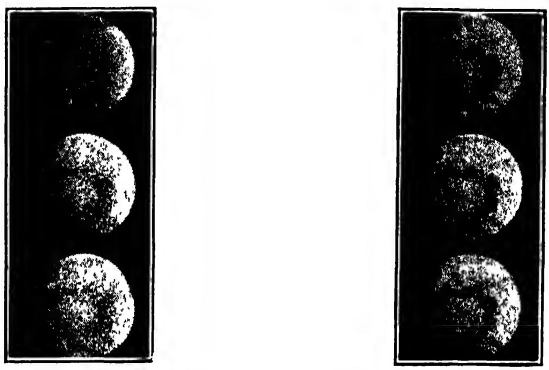
Note the irregular shapes and sizes and also the folded condition.

milk very fine; others, rather coarse. The apparent size is larger for flaky powders than for spherical ones. In the samples examined, the larger flakes measured 0.4 to 0.9 mm. in length and 0.15 to 0.6 mm. in width at the broadest point, many being triangular. The smallest pieces of flaky powders measured only 1.5 microns. The thickness of the flakes is very hard to measure, as they are so much folded and the thickness is so small. The thickness is in general probably less than 10 microns, depending, of course, on the method used in drying. If fresh milk is directly supplied to the drum, the film of milk must be very thin and the dried flakes must necessarily have a very small thickness; while, when milk is previously condensed, the resulting powder flakes must be comparatively thick. The flakes of Australian milk powder, from actual measurement made by various methods, are about 8 microns thick. Because they are thin, folded, and irregular in shape, a comparatively large surface is exposed. Therefore, a greater portion of the fat is attached to the surface. When a flake is suspended in cold water, it first swells and the attached fat assumes a globular shape; the fat globules then gradually detach themselves from the flake. The fat globules are much larger than those of powdered milk made by the spray process; in fact, they are generally larger than those of the original milk.

FIG. 57.—DOUGH-PROCESS POWDER GRAINS. Heavily sweetened, containing nearly 50 per cent sucrose.

Solubility.—It is always claimed by manufacturers of powdered milk that their products are entirely soluble in water, and that when they are dissolved in the proper amount of water, the resulting fluid is the same as fresh milk in all respects. The fact is that many are very insoluble, even in warm water, and the

majority do not readily dissolve in cold water. The term solubility, as herein used, is applied to the state of colloidal dispersion of the casein of powdered milk in water. Apparent solubility and absolute solubility are conflicting. Flaky powders have a better apparent solubility, and fine spherical powders always have a poor apparent solubility when water is added to the powder. In reality, however, the latter have a better solubility. The absolute solubility may best be examined by placing a grain of powder on a glass slide under a cover glass, placing the slide under the microscope, and focusing. A drop of water is then run in with a capillary tube between the slide and cover glass. The grain of powder is watched. When the water reaches a grain of



Appearance of Fat Globules — Disappearance of Fat Globules

FIG. 58.—KINEMATIC PHOTOMICROGRAPHS OF DRUM-PROCESS POWDER GRAINS IN 80 PER CENT ALCOHOL.

Note the fat globules in the first group of pictures, and their disappearance in the second, on the addition of ether. This shows that fat globules are on the surface of the grains.

freely soluble powder, the grain at once loses its shape and a cloudy stream of fat globules is formed. A grain of poorly soluble or insoluble powder will simply swell on meeting the water, and only the attached fat assumes globular shape, running away very slowly.

A simpler way of judging the real solubility of powdered milk is by a test-tube method. Water is first put into a test tube, the tube being filled nearly to the top. A little powder is placed on top of the water. An easily soluble powder commences at once to

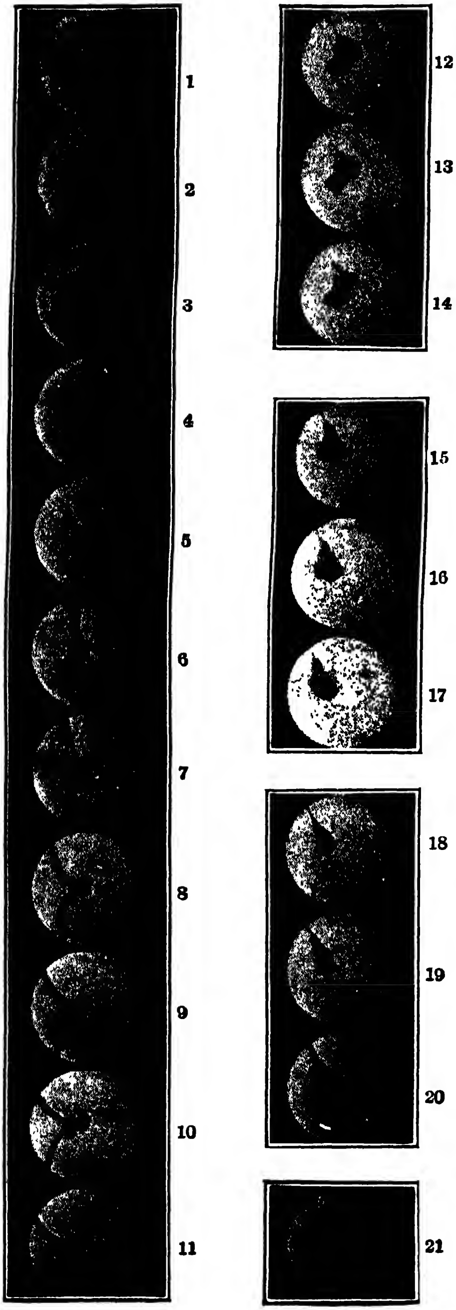


Fig. 59.—Kinematic Photomicrographs of Spray-process Powder Grains.

A film of water was permitted to flow between the slide and the cover glass. The progress of the edge of this film is shown in Nos. 1 to 11. Nos. 12 to 14 show the beginning of solution; 15 to 17, about the middle; and 18 to 20, the last stage of solution. In 21 the grain is all dissolved, leaving only two air bubbles which were between the powder grains.

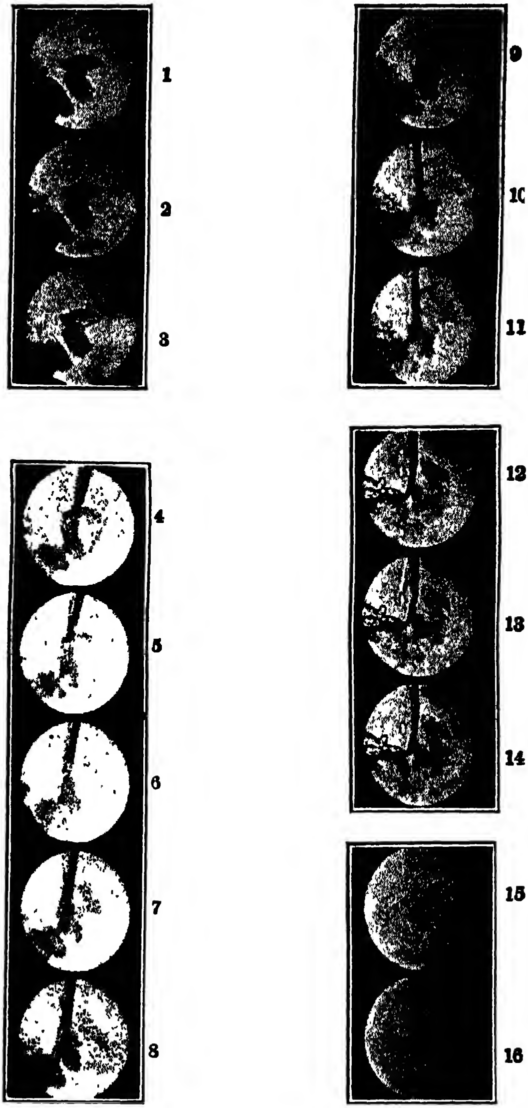


FIG. 60.—KINEMATIC PHOTOMICROGRAPHS OF DRUM-PROCESS POWDER GRAINS.

Nos. 1 to 3 are the original grains; 4 to 8 show successive steps as water flows in; 9 to 11, the swollen condition of the grains. In 12 to 14, fat globules appear, and in 15 and 16 are shown the undissolved fragment remaining, the other portion being swept away by the flow of water.

disperse in white milky streams, first downward and then upward. The water soon becomes milky. Poorly soluble powders do not disperse in water. They either remain floating on top or gradually drop down, piece by piece, or else the mass settles on the bottom of the tube. The water remains clear for a long period with very insoluble powders; it becomes cloudy on long standing with slightly soluble powders. Experience shows that powdered milk manufactured by the spray process is usually more soluble than that made by the drum process. Powdered milk made by

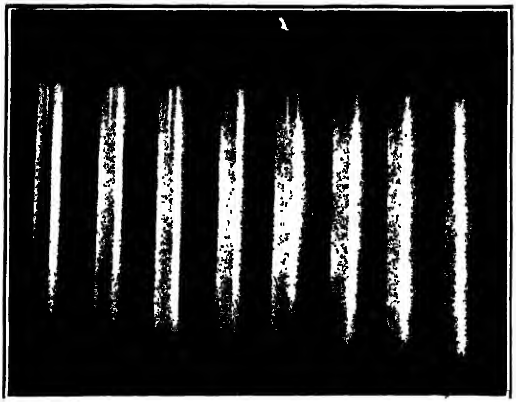


Fig. 61.—Comparative Solubility.

Five grams of powdered milk were placed on top of 50 cc. of cold water in each test tube, and left undisturbed for seven hours. Then the photograph was taken. Some powder remains on top of Nos. 1 and 2. The others show almost complete solution. Test tubes 1 and 2 are Klim, 3 and 4 Kintaro, powdered whole milk, 5 and 6 Kintaro with 14.4 per cent sucrose, 7 and 8 Kintaro with 53 per cent sucrose. All samples were made by spray processes.

the dough process is usually very insoluble as far as the dispersion of casein is concerned. The sugar is soluble in all cases, without question. There are, of course, exceptions to the above statement. There was a certain brand of powdered milk, made by the spray process, which was almost insoluble. The manner of manipulating the milk in drying and the kind of drying machine may have different effects on solubility.

When hot water is added to the powdered milk manufactured by the present improved methods, it usually dissolves fairly well.

In the case of spray-process powders, lumps are often formed and the powders do not dissolve very readily on account of their fineness. To dissolve such powders, it is best to add a little water at first and work to a pasty condition; then water is gradually added and stirred until the desired amount of water has been added and all the powder dissolved. If the powder is to be dissolved in a bottle, it is best to put the desired amount of water into the bottle first and then measure the powder and add it on top of the water. If the stoppered bottle is vigorously shaken, the powder usually dissolves very quickly and completely. An elec-

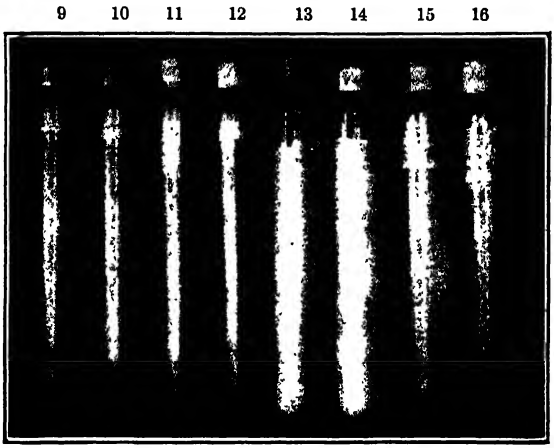


FIG. 62.—COMPARATIVE SOLUBILITY.

Five grams of powdered milk were placed on top of 50 cc. of cold water in each test tube and left undisturbed for seven hours, and then the photograph was taken. Note the clearness of the water in test tubes 9, 10, 11, and 12, all of which are drum-process powders. In 13 and 14 there is a little undissolved powder on top while in 15 and 16 there is slight solution, with much undissolved powder remaining on top. Test tubes 9 and 10 are Morinaga, 11 and 12 Lactogen. The other four are spray-process powders, 13 and 14 being Darigold and 15 and 16 Bonalac.

tric mixer, such as that used at soda fountains in mixing malted milk, is very useful in dissolving powdered milk.

Hunziker [29] states that the solubility of powdered milk varies principally with the quality of the fluid milk and with the process of manufacture. By quality of milk he refers chiefly to the acidity. Heat combined with high acidity destroys the solubility of casein and ash constituents. The fresher and sweeter the milk at the

[29] Hunziker, O. F., Condensed Milk and Milk Powder, 4th Ed., pp. 480, 481.

time of desiccation, the more soluble will be the powder, other factors being the same. He puts much stress on the acidity of the milk. There is no question that very fresh and sweet milk is essential in making the first-grade product of highest solubility, and developed acidity is unfavorable for solubility of powdered milk, as Hunziker states. The original acidity, however, has nothing to do with the solubility of the powder. The ash balance of the original milk is of even greater importance in the solubility of powdered milk. The resistance to heat and desiccation is greatly influenced by disturbance of ash balance.

17 18 19 20 21 22 23 24 25 26

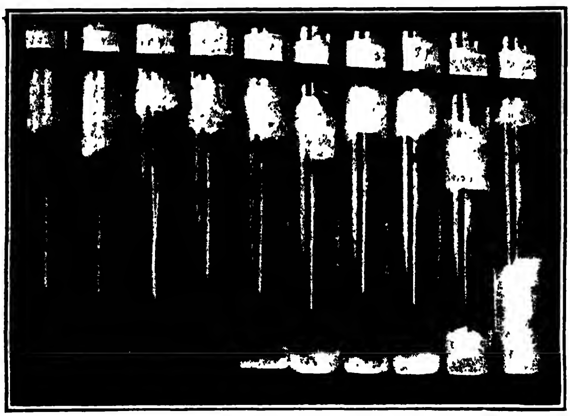


FIG. 63.—COMPARATIVE SOLUBILITY.

Five grams of powdered milk were placed on top of 50 cc. of cold water in each test tube and left undisturbed for seven hours. The photograph was then taken. Note clearness of water in all tubes, with undissolved powder either on top or settled on the bottom. Test tubes 17 and 18 are Homogen, 19 and 20 Glaxo, and 21 and 22 Oshidori. These are all drum-process powders. Numbers 23 and 24 are Dog Brand, and 25 and 26 Hinode. These two brands are made by the dough process.

The degree of heat applied and the manner of applying it govern the solubility more than any other factors, provided the original milk is perfectly fresh. Hunziker states that powdered milk made by the drum process is more unfavorably affected by heat than that which is made by the spray process, the latter being thus more soluble. In the drum process, the milk is in direct contact with a highly heated metal surface, while in the spray process the milk is not exposed to a steam-heated metal surface. The fact that the air entering the spray-drying chamber may have

a temperature of 275° to 300° F. does not appear to affect materially the solubility of the resulting powder. The evaporation of water in the atomized spray is so rapid that it has a marked cooling effect, and it is believed that the milk solids are kept in a relatively cool condition until they have surrendered practically all of their water. The air is also cooled down on account of the latent heat of evaporation absorbed by the evaporating water, and the temperature of the chamber may be as low as 170° F. to 180° F. Such temperatures do not have the same unfavorable effect on the milk solids when they are in a perfectly dry state as when they are wet. It is a matter of common knowledge that the casein of milk is rendered insoluble when it is exposed to a high temperature at a certain degree of concentration. In the spray-drying process, the change from a state of high concentration of fluid milk to complete dryness is so instantaneous that the solubility of the casein is not materially affected.

Miscibility.—Hunziker distinguishes the solubility of milk powder in water from its miscibility. He states that, other conditions being the same, it is obvious that the finer the particles of the powder the more rapidly will it dissolve, and he attributes this to the greater surface of the powder in proportion to its cubic content. This is perfectly true as far as the theory is concerned. But when he applies this theory to the explanation of the ready solubility of powders manufactured by the spray process, there seems to be a mistake. The difference in the miscibility of powders made by the two methods in water seems to be due to the difference in real solubility, and not merely to the relative surface exposure.

Hunziker again states that the spray-process powders are usually finer and more flaky than those made by the film process, hence the former should go into solution more rapidly than the latter. As stated before, the grains are usually smaller in spray-process powder. But it is not safe to draw such a conclusion from linear or diametrical measurement alone. If the grains of both kinds of powders are exactly the same in shape, it may hold true. In reality, the spray-process powder grains are spherical in shape and not at all flaky. These spheres are much more solid than drum-process powder grains, which are really flaky. The following table shows the surface in square millimeters, the volume in

cubic millimeters, and the volume per square millimeter of surface exposed, of spheres 10 to 50 microns in diameter, within which limits the powders of the spray process lie.

RELATION OF VOLUME TO SURFACE OF SPHERE

Diameter, Microns	Surface, Sq. Mm.	Volume, Cu. Mm.	Volume per Sq. Mm.
10	0.00031	0.00000052	0.0017
20	0.0013	0.0000042	0.0033
30	0.0028	0.000014	0.0050
40	0.0050	0.0000335	0.0067
50	0.0078	0.000065	0.0083

It is a well-known fact that, of the surfaces capable of enclosing a given volume, the smallest is a sphere. The flaky powders made by the drum process have very irregular shapes, and their surfaces are folded and rough. Therefore, the surface exposed for a given volume must be greater. As the foregoing table shows, the volume per square millimeter of a sphere depends on the diameter, being less for smaller diameters. Therefore, with two powders of the same kind, the finer powder naturally dissolves more quickly than the coarser one. The flaky powders usually look larger, because they have larger linear measurements. Their volume is not so large as one might imagine, however, as the thickness of the flaky grains has already been stated to be less than 0.01 mm. They often look quite thick, simply because the surface is folded. The following table shows some measurements made on the surface, the absolute volume, and the volume per square millimeter of surface, of flaky powders made by the drum process.

RELATION OF VOLUME TO SURFACE OF FLAKY POWDERS

Dimensions, Mm.					
Length	Width	Thickness	Surface, Sq. Mm.	Volume, Cu. Mm.	Volume per Sq. Mm.
0.4	0.25	0.005	0 21	0.0005	0.0024
0.4	0 25	0 010	0 21	0.0010	0.0047
0.6	0.15	0.005	0 13	0.00045	0.0024
0.6	0.15	0 010	0 19	0.00090	0.0046
0.87	0.60	0.005	1.06	0.00262	0.0024
0.87	0.60	0.010	1.08	0.00525	0.0048
0.37	0.18	0.005	0.13	0.00032	0.0024
0.37	0.18	0 010	0.14	0.00064	0.0047

In the above figures it is assumed that the flakes are of a smooth, rectangular shape. In reality, they are not at all so. Therefore, the real surface is much greater than that given above, and the volume per square millimeter of surface is much smaller than in the above calculations. There is no way of calculating the exact surface and volume. In this discussion it will be assumed that the powder flakes are planes. The above measurements are of usual sizes of flakes actually measured under the

FIG. 64.—MICROSCOPIC VIEW OF WATER-INSOLUBLE POWDER GRAINS.
The grains simply swelled in water.

microscope, except the thickness, which is assumed to be either 0.005 or 0.01 mm. If the thickness of the flakes is only 0.005 mm., powders made by the drum process have much less volume per square millimeter of surface exposed than powders made by the spray process. If, however, the thickness is 0.01 mm., the volume per unit surface is about equal to that of smaller-sized powders made by the spray process. In other words, the surface exposed per unit volume is usually greater for drum-process powders than for spray-process powders. At the best, the surface per given volume of drum-process powders equals that of spray-process powders, in spite of the fact that the latter are much finer powders.

Therefore, Hunziker's explanation of the better solubility of spray powder does not seem to be justified.

As stated before, drum-process powders usually do not redisperse in cold water. They simply swell on contact with water. The degree of swelling depends on many factors. An Australian brand of powdered milk, which is manufactured by a drum process, was examined under the microscope. A grain of the powder was placed between slide and cover glasses and its linear measurement was taken. Water was then introduced by a capillary tube and the swelling of the grain observed. After a few seconds, when the swelling was completed, the linear measurement was again taken. The results of some of the measurements are given in the following table.

SWELLING OF POWDERS MADE BY DRUM PROCESS

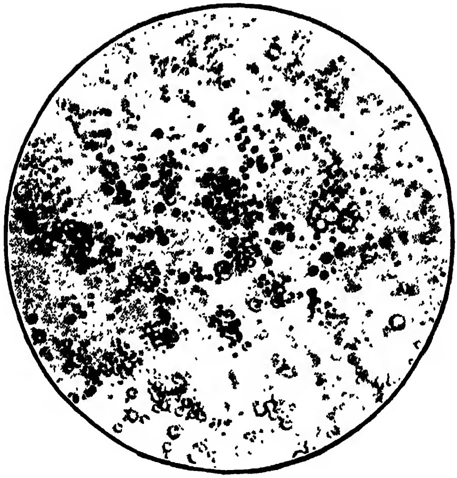
Sample No.	Linear Measurement of Grain: In Dry State, Mm.	Linear Measurement of Grain: After Addition of Water, Mm.	Percentage of Swell
1	0.515	0.725	41.0
2	0 950	1 150	21 0
3	0 260	0.400	54.0
4	0 615	0 800	30.0
5	0 250	0.300	20.0
6	0 150	0.250	67.0
7	0.190	0 250	32.0
8	0 135	0 170	26 0
9	0 175	0 250	43 0
10	0 210	0 300	43.0
Average	0 345	0.4595	37 7

As seen above, powders swell, on addition of water, from 20 per cent to 67 per cent (linear measurement). The average linear swell. is 37.7 per cent for an average linear measurement of 0.345 mm. This means an increase in surface of about 90 per cent, and in volume of about 162 per cent. Therefore, the powders really swell to about two and a half times the dry volume.

Observations show that thinner and smaller flakes usually swell more and faster. It is also observed that, on swelling, the powder often breaks up, especially the thinner flakes. When the powder breaks into fine particles, they float around suspended in water, a part going into colloidal solution, and the greater portion

being simply suspended. Even those particles that are still in a state of suspension may pass through an ordinary filter when they are very fine. When water-suspended powders are well shaken, the swollen bodies are subdivided very finely, and an apparent solution is obtained; but, on standing, the greater portion of the suspended particles settle. If the settled portion of the powders is separated out and fresh water is again added and the contents shaken, a further solution is obtained, and by a repetition of this process practically all may be put into apparent solution.

Hunziker states that the concentration of milk at the time of spraying influences the coarseness or fineness of the spray to a considerable extent. Other conditions being the same, he declares, the higher the concentration of the milk the coarser the spray, and the less flaky and more granular the resulting powder. He further says that when the milk is sprayed before being condensed, a finer and flakier powder is produced than when the milk is previously condensed, other conditions being the same. Generally speaking, Hunziker's statements are true; but experience in manufacturing powdered milk by the spray method and in examining the resulting powders does not always bear out his statements, especially the last. The powdered milk made by directly spraying fresh milk is not so distinctly finer than that made by spraying precondensed milk, and it is not at all flaky. Careful examination of powdered milk manufactured by direct spraying shows that powder so dried is not very solid, but is rather spongy. In other words, there are more and larger air cores in a powder grain. Therefore, such powder is lighter and is difficult to dissolve on account of its tendency to float. Powdered milk manufactured in the same way is also difficult to dissolve on account of the condition of its fat. The fat globules are not at all homogenized by spraying milk directly, as they usually are by spraying precondensed milk. Instead, there is a tendency for the fat globules to stick together, causing " oiling off " on reconstitution in much the same way as with powdered milk made by the drum process. The physical condition of the fat has an influence on the miscibility of powders. When milk is precondensed prior to spraying, the fat globules are usually homogenized, but the fat globules of drum-process powders are not homogenized at all; instead, their globular form is destroyed, and upon dissolving they " oil off."



Original whole milk.

FIG. 65.—RECONSTITUTED SPRAY-POWDERED MILK MADE FROM MILK SPRAYED WITHOUT PRECONDENSING.

Note the difference in sizes of fat globules. By precondensing, the size of the fat globules tends to increase; but on spraying the fat globules are homogenized. The samples shown in Figs. 65 and 66 are from the same original whole milk.

Precondensed milk.

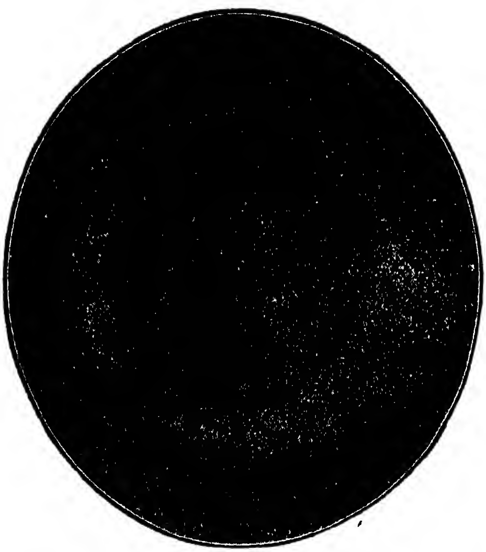
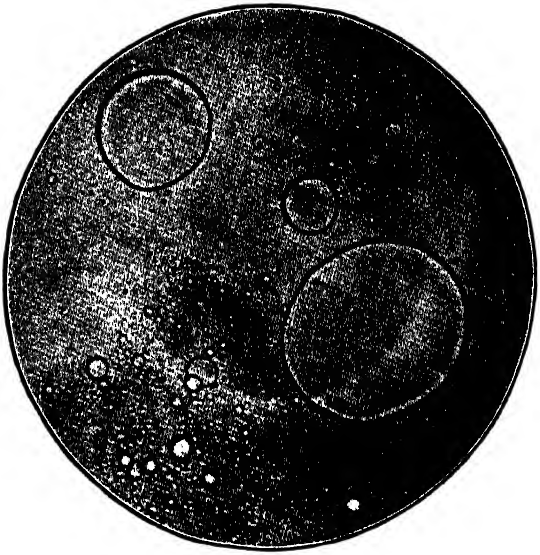


Fig. 66.—Reconstituted Spray-powdered Milk Made from Precondensed Milk.



Lactogen.

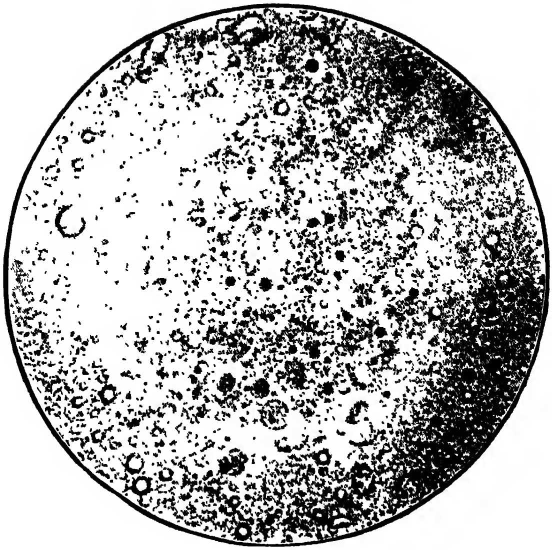
Homogen.

FIG. 67.—FAT GLOBULES OF POWDERED MILK MADE BY
Compare with photomicrographs of the fat globules of original,
the insoluble portions of casein

Glaxo.

Morinaga.

DRUM PROCESSES, RECONSTITUTED WITH HOT WATER.
precondensed, and spray-dried powdered milk. Note also
in Lactogen and Glaxo.



Oshidori Brand.

Dog Brand.

FIG. 68.—FAT GLOBULES OF POWDERED MILK DISSOLVED IN HOT WATER.

Both powders are made by dough processes. The fat globules are larger than those of spray-process powders. All photomicrographs are comparable, as they are made at the same magnification.

The greater miscibility of powdered milk made by the spray process is due not to the size of the powder grains, but primarily to the greater solubility of the powder and to the homogenized condition of its fat globules.

Insoluble Matter of Powdered Milk.—The insoluble matter of powdered milk consists of coagulated protein, insoluble ash, and dirt. Hunziker,[30] in discussing the solubility of powdered milk, gives the following table, showing the solubility of samples made by drum drying and by spray drying.

SOLUBILITY OF MILK POWDERS OF FILM DRYING PROCESS AND OF SPRAY DRYING PROCESS

Process of Desiccation	In Cold Water at 78.5° F.		In Hot Water at 210° F.	
	Per cent in Solution	Per cent of Powder Dissolved	Per cent in Solution	Per cent of Powder Dissolved
Film process powders				
Skim-milk powder	3.94	69.61	4.42	78.09
Cream powder	3.46	61.13	4.53	80.03
Spray process powders				
Skim-milk powder (milk heated to 150° F. before drying)	5.61	99.12	5.76	101.76
Skim-milk powder (milk heated to 210° F. before drying)	5.09	88.16	5.33	94.17

According to the above figures, the drum (film)-process powders were very insoluble in cold water, leaving about 30.39 per cent insoluble matter in skimmed-milk powder and 38.87 per cent in cream powder. Even with hot water, the insoluble matter was 21.91 per cent in skimmed-milk powder and 19.97 per cent in cream powder. The spray-process powders, in cold water, left only 0.88 per cent insoluble matter in skimmed-milk powder made from milk heated to 150° F. previous to drying. When the milk was heated to 210° F. before spraying, the powder was much less soluble, and the percentages of insoluble matter were 11.84 in cold water and 5.83 in hot water.

[30] Hunziker, O. F., Condensed Milk and Milk Powder, 4th Ed., p. 486.

The terms " solubility " and " miscibility " as applied to powdered milk in water, are difficult to define and distinguish from each other. Hence it is very difficult to show figures for either solubility or insolubility, and methods of determining them are uncertain. Hunziker's figures were obtained by adding 12 grams of powder to 200 cc. of water at a temperature of 78.5° F. The mixture was placed in a mechanical shaker and shaken for ten minutes. For the determination of solubility in cold water, 100 cc. of the mixture were poured through a filter paper and the filtrate analyzed for percentage of total solids. For determining the solubility in hot water, 100 cc. were heated to the boiling point and held there for five minutes. The water lost by evaporation was replaced. The hot solution was then filtered and analyzed for total solids. With this method, the results are very variable and uncertain.

Dobbie[31] reports percentage solubilities of powdered milk collected on the London market.

SOLUBILITY OF POWDERED WHOLE MILK

Number of Samples	Percentage Solubility
3	96-100
2	91- 95
7	86- 90

SOLUBILITY OF POWDERED SKIMMED MILK

Number of Samples	Percentage Solubility
10	96 100
10	91- 95
14	86- 90
10	81- 85
4	76- 80
4	71- 75

He employed a centrifugal method in separating the insoluble matter from the solution. The total solids in solution were determined. This method is very useful, but the results are not absolute, as unskillful manipulation of the method may bring poor results.

Supplee and Bellis[32] studied the solubility of powdered milk as affected by moisture content. They showed that the develop-

[31] Dobbie, James J., Rept. to Local Govt. Board, Food Rept., No. 24.

[32] Supplee, G. C., and Bellis, B., Jour. Dairy Sci., Vol. VIII, 39, 1923.

ment of insolubility of the protein of powdered milk during storage is due to the presence of moisture. The higher the water content, the more the solubility is affected. Supplee and his associate, however, studied the solubility of the protein only. The solubility or insolubility of powdered milk does not depend only upon the protein.

The insoluble matter in the powdered milk found on the Japanese market was also studied. In the endeavor to find the true insoluble matter in powdered milk, it was found that the methods previously used were unsatisfactory. Therefore, a special method was devised. A weighed amount of powder was dissolved in warm water (not hot, in order to avoid coagulation of proteins) and the liquid was filtered through a previously prepared and tared Gooch crucible filter. It was washed with warm water until there was no trace of protein in the filtrate. The residue was washed with absolute alcohol to take off the moisture. Then it was washed with ether to take off any fat remaining with the residue or absorbed in the asbestos. After drying, the residue, or the insoluble matter, was weighed. This direct method of determining the insoluble matter in powdered milk gave much more constant results, for the same sample, than any other methods of the kind. When there was any difference in duplicate determinations, it was within the probable error.

The greatest amount of insoluble matter was found, by the above method, in samples made by dough processes. The drum-process powders contained more insoluble matter than the spray-process powders.

Insoluble Matter in Powdered Milk

Process	Percentage of Insoluble Matter	Number of Samples
Spray.	0 71-1.16	4
Drum	0.85-2 57	4
Dough........	1.63-5.36	3

It was found that, by prolonged washing with warm water, most of the protein could be made to pass through a Gooch crucible filter. Only coagulated and absolutely insoluble proteins remained in the residue.

The insoluble matter is increased, as stated, on storing, when the moisture content is high. Powdered milk with a small moisture content does not increase its insoluble matter materially on keeping. In connection with an experiment on the keeping quality of powdered milk made by a spray process, the insoluble matter was also determined. The samples were variously packed and incubated at 37° C. for three, six, and nine weeks, and then analyzed. The average of all results on content of insoluble matter is summarized in the next table.

INFLUENCE OF INCUBATION ON PERCENTAGE OF INSOLUBLE MATTER

	Incubated at 37° F. for		
	3 Weeks	6 Weeks	9 Weeks
Moisture, per cent	1 33	1.35	1.44
Insoluble matter, per cent	0 62	0 66	0.70

If the moisture content is kept down, the solubility can be kept almost intact during the storage period.

In the insoluble matter of powdered milk, dirt was a share. Dobbie[33] reports the amount of dirt found in samples of powdered milk.

AMOUNT OF DIRT IN POWDERED MILK

Per Cent	Number of Samples
Nil	2
0 01	15
0 02	14
0.03	14
0 04	9
0 05	4
0 07	3
0.08	1
0 10	1
0.19	1

Dobbie states that the microscopical examination showed the dirt to be composed of sand, sawdust, dyed and undyed vegetable fibers, animal hairs, fragments of feeding stuffs, charred organic substances, and débris of animal tissue.

[33] Dobbie, James J., Rept. to Local Govt. Board, Food Rept. No. 24, 173.

Hygroscopic Property of Powdered Milk.—Powdered milk is very hygroscopic. When left exposed to the air, it will absorb moisture, the amount of absorption depending on the humidity of the air. The moisture content of powder made by the spray method may be less than 1 per cent; but, on being taken out of the drying chamber, the powder will at once absorb moisture from the outside air, and unless care is taken the moisture content may rise high before packing.

Samples of powdered milk were first made free from moisture in a drying oven, and then were left exposed to the air. The moisture absorbed was determined every twenty-four hours for four consecutive days. The results of the findings are given in the following table.

Absorption of Moisture by Powdered Milk

Sample No.	1st Day	2nd Day	3rd Day	4th Day
1	9.84	8.96	8.35	8.09
2	10.85	8.76	7.96	7 43
3	12.45	11.58	10 57	10.20
4	5.38	4.15	3 57	3 33
5	11 69	11 27	10 32	9.87
6	9.35	8.15	7 64	7.71
7	10 23	10 77	10 40	10 28
8	10 86	9.05	8 43	8 26
9	8 37	7.77	7.47	7.36
10	10.51	9 51	8.88	9.27
11	4.89	4.89	4.53	4.52
12	4.41	4.56	4.17	4.08
13	6.90	8.13	7.97	7.93

The table above shows that most of the moisture is absorbed within the first twenty-four hours. After that the powder may lose some of the moisture it has absorbed, depending on the humidity of the air. A considerable difference in the hygroscopic property of different samples may be noticed. This is due to the condition of the powders after being dried in the drying oven, and to their composition. Sweetened powders, in which the sucrose has been added to the milk before drying, are very hygroscopic. If sweetened condensed milk is sprayed and dried, the powder is exceptionally hygroscopic. When left in the air, the powder becomes very wet within a few minutes, in wet weather

or in moist air. This powder, however, upon drying in an oven at boiling temperature, does not absorb moisture so readily. This seems to be due to the fact that the sucrose is caramelized and the powder made a more amorphous mass. The powders with

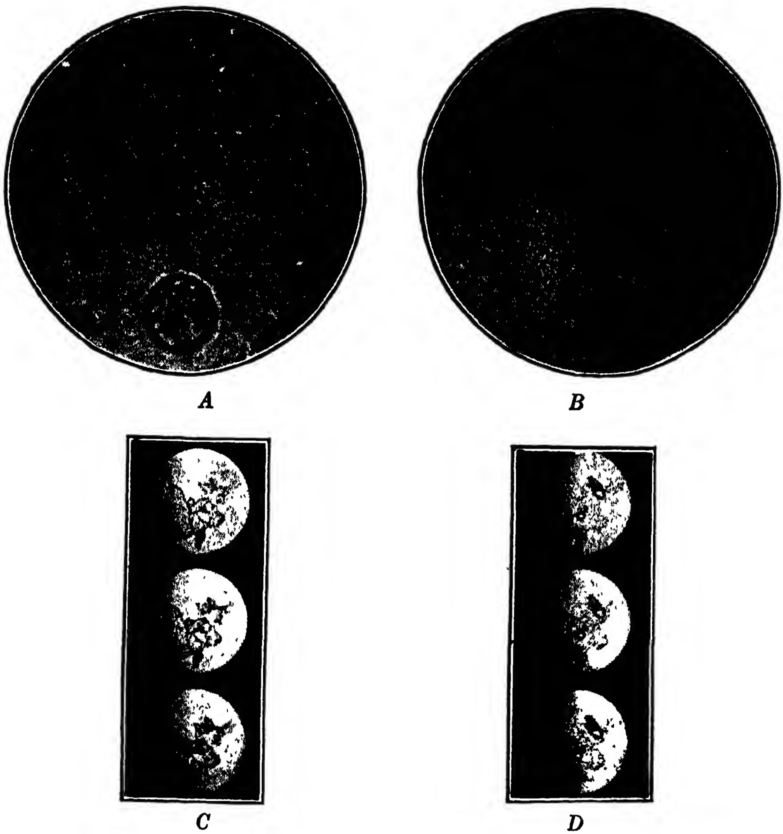


Fig. 69.—Grains of Milk Powder with Water.

In *A* and *C* the grains have just been wetted. In *B* and *D* the grains have remained wet for a few seconds. The globules of fat are plainly visible in *D*, which is a drum-process powder. In order to show the fat globules in *B*, which shows grains of spray-process powder, the magnification is five times as great. The tiny protuberances around the grains in *B* are the fat globules.

about 15 per cent sucrose are more hygroscopic, after complete drying in an oven at boiling temperature, than ordinary unsweetened powders. The following table shows the averages of unsweetened and sweetened powders.

Absorption of Moisture of Unsweetened and Sweetened Powders

	1st Day	2nd Day	3rd Day	4th Day
Unsweetened powder	9.49	8.79	8.32	8.15
Powders with 15 per cent sucrose	11.55	10.79	9.92	9.78
Powders with 50 per cent sucrose	4.89	4.53	4.09	3.97

Oiling off of Fat on Reconstitution.—On reconstituting powdered milk, a perfect milk is obtained from some powders; but in many cases the fat separates out and floats on top, either in granular form or in an oily condition. With drum-process powders, this phenomenon is almost always observed in greater or less degree. With spray-process powders it is not observed in most cases. In the latter, the fat globules are in a very finely divided state, much finer than the fat globules in the original milk. This is due, as stated before, to the homogenizing effect of spraying. When, however, milk is directly sprayed without precondensation, no homogenizing effect takes place in spraying, and the resulting powders show the separation of fat on reconstitution. Out of thirteen samples studied, there were four in which fat separated out. These four were all drum-process whole-milk powders. The rest were either spray or dough-process powders, all of the dough-process powders being skimmed-milk products. There were six brands of spray-process powders, most of which were either whole-milk or slightly skimmed products, one being a skimmed-milk product.

Since the fat is homogenized in ordinary spray-process powders, the cream will not rise on reconstituting. On long standing, however, a very slight cream line may be noticed. This often misleads the consumer to think that spray-process powders are all skimmed-milk products. The flavor is very rich, however, when the whole-milk spray powder is reconstituted, distinguishing it from the skimmed-milk product:

On account of the homogenizing effect of the spraying process, the minute fat globules are embedded in compact granules of milk solids, and it is very difficult to extract the fat of spray-process powders with ether by the ordinary extraction method. This has led some investigators to report certain spray-dried whole-milk powders as skimmed-milk products.

Action of Rennet.—When milk is heated, the rennet action is retarded, if not lost. The action of rennet on reconstituted milk from powdered milk varies considerably. Since a complete solution cannot be made with drum-process powders, a firm and even coagulation cannot be obtained. On the other hand, with some spray-process powders, a comparatively smooth and firm curd, much resembling the curd formed with fresh milk, is formed by the addition of rennet. The degree of change in the properties and constituents of powdered milk from fresh milk may be to some extent determined by the rennet test.

Monier-Williams[34] points out that the curd produced by rennet in the reconstituted milk is quite unlike that produced in fresh milk. While the latter is firm, tough, and cohesive, the former is flocculent and finely divided. Other investigators, including Maclaurin, Jaquet, and Huyge, report similar results. Sommerville stated that rennet gave reconstituted dried milk a granular precipitate instead of a firm clot. He considered this phenomenon to be due to a modification of casein and to be useful in infant feeding. Porcher and Cazulas stated that reconstituted dry milk coagulated with rennet just like human milk. Porcher again referred to the fact that the reconstituted dry milk could not be made into cheese with rennet, and also stated that if, to reconstituted dry milk plus rennet, there was added a small quantity of a soluble salt of calcium, notably the chloride, a firmer clot could have been obtained, thus suggesting that the modification of calcium salts is one of the causes of the changes in the reaction of rennet.

Peroxydase Reaction.—The peroxydase reaction with either paraphenylenediamine or guaiacum tincture is observed in order to test the heating of fresh milk. A fresh milk should give a marked coloration, while a milk heated to a temperature higher than 170° F. does not give a color, as the peroxydases are said to be destroyed at this temperature. This test may also be applied to reconstituted milk to test the presence of peroxydases, thus giving a clue to the degree of heating to which the milk has been subjected during the process of manufacture. Experiment shows that most of the powders do not produce coloration. Some spray-process powders, Klim and Kintaro brands, for instance, both of

[34] Monier-Williams, G. W., Rept. to Local Govt. Board, Food Rept., No. 24.

which are manufactured by the Merrell-Soule process, produce a distinct coloration. Some drum-process powders, especially those made by the Buflovak process, give a slight coloration.

The presence of peroxydases is governed primarily by the heat applied in the manufacturing process, but it is also determined by the exposure of powdered milk to air; hence the degree of color change is also an indication of the age of powdered milk, provided the fresh powder has been positive to the reaction. When powders are sealed in tin cans, the peroxydases may survive for years, as experiment shows that powders made by the Merrell-Soule process produce a very distinct and strong coloration after one year's storage in an ordinary room. When the tin can is opened and the powder is exposed to free air, the reaction is gradually diminished.

Some methods of packing tend to preserve the activity of peroxydases in powdered milk. Samples packed in vacuum, and those packed with hydrogen, oxygen-free air, and carbon dioxide gases were compared, the control being packed in tin cans with air. The samples were incubated at 37° F. for three, six, and nine weeks. The reactions were read as strong, medium, and weak, the number of occurrences being listed.

Peroxydase Activity in Powdered Milk

	Reaction after Incubation at 37° F.		
	Strong	Medium	Weak
Control, or air-packed	6	2	7
Vacuum-packed in light bottles	8	2	5
Vacuum-packed in brown bottle	10	2	3
Hydrogen-packed	11	2	2
Oxygen-free air packed	8	3	4
Carbon dioxide packed	8	2	5

Of fifteen tests made, the control lot gave six strong reactions, two medium, and seven weak. All the samples packed otherwise showed greater numbers of strong reactions. This proves that the action of peroxydases in powdered milk is weakened by storing or packing the powdered milk in the presence of air.

Monier-Williams[35] states that reconstituted milk tested with metaphenylenediamine and hydrogen peroxide produces no color, whereas fresh milk gives the blue coloration due to the presence of

[35] Monier-Williams, G. W., Rept. to Local Govt. Board, Food Rept., No. 24, 26.

peroxydase. He says, further, that it is probable that the reconstituted milk does not contain the active enzyme of fresh milk.

Dahle and Palmer [36] studied the effect of storage on the peroxydase activity of powdered milk. They found that the factors known to favor oxidation, such as air, heat, and moisture, proved detrimental to peroxydase activity in the powders studied. They had previously reported that certain milk powders exhibited greater peroxydase activity than others: the enzyme was inactive in the case of drum-made powders dried under atmospheric pressure, but active when these powders were dried under reduced pressure or in a vacuum. Spray-made powders showed pronounced evidence of the presence of the enzyme. These statements agree with the results of the test made in the author's laboratory.

Dahle and Palmer further state that powders stored under vacuum, and those stored in containers that prevented the entrance of air and moisture, showed greater peroxydase activity than samples of the same powders stored in containers that permitted the entrance of air and moisture. Increasing the moisture content of the powders by exposing them to an atmosphere nearly saturated with moisture was very detrimental to peroxydase activity. No activity could be detected after three months in storage at 4° C., 20° C., and 37° C. High storage temperature and high moisture content greatly accelerated the rate of destruction of the enzyme. All these findings agree with the results obtained at the author's laboratory.

KEEPING QUALITY OF POWDERED MILK

The keeping quality of articles used for food is very important. The difficulty experienced in establishing powdered milk as a commercial dairy product was due to its poor keeping quality, especially that of the whole-milk product. Even at present, it is impossible to manufacture powdered milk that keeps perfectly.

Effect of Moisture.—Some of the factors affecting the keeping quality of powdered milk have already been discussed. Properly dried milk has very little moisture, and is not subject to bacterial deterioration. Therefore, if the product is properly packed and

[36] Dahle, C. D., and Palmer, L. S., Jour. Dairy Sci., Vol. VII, 141.

stored at a low temperature, it should keep reasonably long in so far as bacterial deterioration is concerned. If the powdered milk contains an excessive amount of moisture, however, or is exposed to dampness, it is likely to become lumpy and moldy and to develop undesirable odors. Dahle and Palmer [37] point out that the powders whose moisture content was increased by exposure to moist air exhibited very inferior keeping quality. They further state that the oxidation of fat, giving rise to a tallowy odor, was the cause of deterioration.

The effect of moisture on the solubility of powdered milk has been discussed.

Effect of Air.—Tallowy and rancid flavors may develop through deterioration by bacterial or enzymic action on moist powders; but powders of very low moisture content, which does not allow bacterial or enzymic activity, are not free from these defects. On aging, the flavor of milk powders becomes poor. The air is the principal cause of this kind of deterioration. The fat undergoes a very slow oxidation on aging, when it is in contact with the oxygen of the air. In the experiment on packing methods, previously referred to, the change in flavor was also noted. Out of fifteen packages, the air-packed samples showed, in eleven cases, the tallowy or rancid flavor; the vacuum-packed samples showed seven cases in light bottles and eight in brown bottles; the tallowy or rancid flavor was noticed only three times in hydrogen-packed samples; six times in oxygen-free air-packed samples; and five times in powders packed with carbon dioxide gas. The above findings show that the presence of air in the package accelerates the development of tallowiness or rancidity. Packing the powders in hydrogen gas was a very effective means of avoiding tallowiness or rancidity in powdered milk.

The air is also responsible for the stale flavor that often develops in powdered milk on keeping.

Effect of Light.—It is generally supposed that light has an unfavorable effect on the keeping quality of powdered milk. The bleaching action of light is the result of a chemical change. The bleaching of the colors of dairy products in general is almost invariably associated with stale, tallowy, and rancid flavors. The exclusion of light is essential to good keeping quality in dairy

[37] Dahle, C. D., and Palmer, L. S., Jour. Dairy Sci., Vol. VII, 40.

products, including powdered milk. Packing in hermetically sealed tin cans or in tightly covered barrels is an effective means of avoiding this defect. The results of the experiments cited in the preceding paragraph do not, however, bear out this assertion, as the powders packed in light vacuum bottles exhibited fewer occurrences of tallowiness than the powders packed in brown bottles. There must have been some other factors affecting the tallowiness besides light. In fact, in that experiment, the bottles were all kept in an incubator most of the time, and the light had almost no chance to act upon the powders. The fact that a sample of powder packed in a light vacuum bottle remained almost unchanged in flavor for more than a year, when it was left in an ordinary room, indicates that light may not change the flavor of powdered milk in the absence of air. Positive statements, however, cannot be made at present, as experiments on this point are not yet complete.

Effect of Heat.—Heat promotes chemical activity. Since the deterioration of ordinary powdered milk is a result of chemical phenomena, a high temperature is probably a frequent cause of rapid deterioration. It intensifies the oxidizing action of air and the activities of other oxidizers and catalyzers. The fact that the incubation of powders at 37° C. accelerates deterioration is a proof of the harmful effect of heat. Dahle and Palmer, in the experiment cited previously, studied the effect of heat on the keeping quality of powdered milk. They state that not much difference was observed between powders stored at 4° C. and 20° C., but a great difference was observed when powders were stored at 37° C.; most of these powders deteriorated very rapidly at the latter temperature and became very hard and discolored. As with other dairy products, it is best to store powdered milk in a cool place.

Effect of Aging.—Chemical changes take place very slowly in milk powders having a very low percentage of moisture. It seems at first that no change is taking place; but on long keeping it is found that the flavor and other properties of the powder are not the same as at the time of manufacture. The solubility, the color, and the flavor are all changed more or less by aging.

Dahle and Palmer[38] found that the effect of time of storage on

[38] Dahle and Palmer, Jour. Dairy Sci., Vol. VII, 40.

the quality of milk powders depended on several factors, including the type of container and the temperature of storage.

Effect of Container.—Dahle and Palmer[39] studied the effect of containers by storing powdered whole milk in small opaque glass jars with metal screw tops, in "Seal-right" paper containers, in plain pasteboard cartons, and in "Doublelite" tin cans, both plain and lacquered. They summarize their results as follows:

Containers permitting the entrance of air proved to be useless for long time storage. Deterioration was very pronounced in samples stored in these containers. Superior keeping quality was observed in samples stored in tin "Doublelite" containers, which provide for absolute exclusion of outside air and moisture. In some cases, samples were practically unchanged after a year in storage. Protection against discoloration due to high storage temperature was afforded when this type of container was used. This was not the case when other containers were used. Lacquered tin cans afforded no better protection than the unlacquered. Tallowy and musty flavors were the main deteriorations observed.

It is very important to pack milk powder in hermetically sealed tin cans for keeping. Paper or pasteboard packages are not suitable. Jensen claimed that powdered whole milk hermetically sealed keeps as well as condensed milk. This statement is perhaps a little too strong, but it shows the importance which Jensen places on the exclusion of air and moisture. Coutts[40] reports that a sample of whole-milk powder, opened in his presence after being sealed in tin for three or four years, was free from rancid odor or flavor, differing mainly from fresh powder in having a slightly stale taste.

Effect of Size and Shape of Powder Grains.—It is well known that the chief factor in the deterioration of milk powder is oxidation. It is natural to assume that the greater the surface exposed to the oxygen of the air, in proportion to the volume of the powder grain, the greater will be the oxidizing effect, other conditions being the same. Coutts says that it is pretty well agreed that powdered milk in an extremely fine state of division, made by a spray-process, does not keep so well as a powder made by a hot-roller

[39] Dahle and Palmer, Jour. Dairy Sci., Vol. VII, 56.

[40] Coutts, F. J. H., Rept. to Local Govt. Board, Food Rept., No. 24, 31.

FIG. 70.—UNCONDENSED SPONGY SPRAY POWDER.

FIG. 71.—PRECONDENSED SPRAY POWDER.

(drum) process. Such statements are often made, but there are many reports to the contrary. In Dahle and Palmer's investigation, three types of powders were used. One type (Klim) represented the pressure spray process known as the Merrell-Soule system. Another (Creamon) represented the centrifugal spray system controlled by the Dick patents. The third (Creamora A), made by the Dry Milk Company of New York, is a drum powder. They found the deterioration of Klim less than that of the other two when in containers permitting the entrance of air. They account for this by the closer packing due to the smaller grains of Klim, and the smaller size of the air pockets in the powder grains.

It is, of course, true that for grains of the same shape, the surface exposed is greater in proportion to the volume in the case of smaller grains. This matter has been discussed in connection with the miscibility of milk powder in water, where it was shown that, although the grains of spray-process powders are smaller, their surface per unit volume is less because of their spherical shape. Also, as has been stated, the smaller grains permit closer packing. Therefore, such powders keep better than those with apparently larger, non-spherical grains. If the spherical grains do not keep well, it must be for some reason other than surface exposure.

Palmer and Dahle,[41] in their studies of the structure of powdered milk in relation to its keeping quality, found air pockets in the grains of spray powders, and they suggest that this is the cause of tallowy deterioration. As has already been mentioned, the number and size of these air cores depends on the concentration of the milk before it is sprayed. In milk powder made from properly precondensed milk, air cores are rare and very small. Ordinarily, an air core does not exceed 10 microns in diameter. Consider such a core in a spherical powder grain 30 microns in diameter. The total surface, outside and inside together, is 0.003 sq. mm., and the volume 0.000014 cu. mm. The volume per square millimeter of surface is 0.0043 cu. mm., which is no less than in the case of drum-process powder. Some of the larger spray-process grains have larger cores, and sometimes more than one in a single grain. Measurements are given of two grains which had two cores in each.

[41] Palmer and Dahle, Jour. Dairy Sci., Vol. V, 240.

MEASUREMENTS OF SPONGY POWDERS

Diameter of Spheres, Microns	Diameter of Air Cores 1, Microns	Diameter of Air Cores 2, Microns	Total Surface Sq. Mm.	Volume of Milk Solids, Cu. Mm.	Volume per Sq. Mm., Cu. Mm.
105	37 5	15	0 040	0 00058	0.0145
90	15 0	10	0 026	0.00038	0.0143

As these two grains were of large size, the volume per square millimeter of surface was even greater than in the case of ordinary solid grains, whether of drum or spray powder. Undoubtedly, air cores are detrimental, but it is not reasonable to attribute so much of the responsibility for deterioration of powdered milk to them as has been done by some investigators.

Effect of Fat Content.—Since the principal defect found in powdered milk, especially that made from whole milk, is tallowiness, and this defect is due to oxidation of fat, the fat content of the powder must naturally influence its keeping quality. Other things being equal, a more rapid and pronounced change occurs in samples having a high fat content. It is often said that powdered whole milk will not keep, and dealers do not guarantee it beyond six months. Some very conservative manufacturers guarantee it only for three months, and so arrange their marketing that the product is consumed within that time. Such care is deserving of high commendation.

Experience shows, however, that well-made and well-packed whole-milk powder often keeps for more than a year, although it is only guaranteed for three months, and at the end of this long period shows no defect of flavor. On the other hand, some powders that are guaranteed by the makers never to deteriorate may become very tallowy shortly after manufacture. Contrary to many reports and claims, defective powders are more often found among those made by drum processes than among those made by spray processes. Skimmed-milk powders keep well unless the moisture content is high. Tallowiness is not so often found in such products.

Haupt considered that the fat of dried milk was affected by the nitrogen of the air and by microörganisms, and that it suffered

decomposition, giving a cheesy or faintly rancid smell to the product. This is very questionable. It is true, however, that a cheesy flavor has developed in some vacuum-packed samples.

Contrary to most findings, Supplee [42] reported that increase in fat content from 5 to 55 per cent showed progressive improvement in keeping quality. Holm [43] and his associates found the reverse to be true with a series of powders varying in fat content from low values up to 33 per cent.

Effect of Homogenizing.—In the Dollar process, patented in 1904, the milk is homogenized before being dried. It is believed by many that this makes the powder keep better. Porcher, however, combats this opinion, holding that the fine state of subdivision of the powders made by spraying milk into hot air offers conditions favoring oxidation, and so causes a tallowy flavor. Porcher's view is not justified, as experiment shows that the spray-process powders in which the fat globules are finely divided actually keep better than those in which the fat is in larger masses, as in direct spraying methods and in drum-process powders.

Washburn,[44] apparently without experimentation, says in his report on physical analysis of dry milk, " The sensitiveness of most spray-process milk powders toward oxidizing agents is augmented by the fact that the atomizing process under high pressure causes a subdivision of the fat globules, depriving the fat of at least a portion of the protective gelatinous layer which surrounds each original fat globule, thereby exposing it more directly to the destructive oxidizing agent." This statement is open to serious question. In the first place, the existence of the gelatinous layer referred to has not been proved. In the second place, the subdivided fat particles are mostly embedded in other milk solids, and only a small porportion is exposed on the surface of the grains in powders made by the high-pressure spray processes. This is shown in the way they behave when an effort is made to extract the fat with ether in the ordinary way. Extraction with a Soxhlet takes out only a small part of the fat. Such powders are far more difficult subjects for fat extraction than drum-

[42] Supplee, G. C., Produce Review and American Creamery, LIX, 482.

[43] Holm, G. E., Greenbank, G. R., and Deysher, E. F., Jour. Dairy Sci., Vol. VIII, 521.

[44] Washburn, R. M., Jour. Dairy Sci., Vol. V, 393.

tallowy. When more than 40 per cent is present, the protective effect is observed.

The addition of cocoa fat is said to help in preventing milk fat from spoiling. No scientific proof of this has been given, but milk chocolate made with powdered milk does not readily turn tallowy or rancid. Both sucrose and cocoa fat are present in this product, as well as starchy and other substances, all of which may have a protective influence on the milk fat.

TECHNIQUE IN MANUFACTURE OF POWDERED MILK

Milk

If they are to be of the first quality, all dairy products demand the best milk. Some defects in the milk supply may be corrected in other cases, but it is futile to use any but the highest-grade milk for milk powder. Rigid inspection must be enforced in the selection of milk for drying.

Pretreatment of Milk.—The pretreatment of milk for drying varies with the process to be used. In some methods, the milk is heated to a certain temperature and at once subjected to the drying process. In others, it is condensed to a greater or less degree and then passed to the drying machine. Correction of acidity with alkali or alkaline salts is sometimes resorted to. This is open to serious objection. Sometimes buffer salts are introduced, to correct the instability of the milk toward heat. This also is poor practice. Instead of correcting the milk in any way, the process should be improved, so as to require no correction when fresh wholesome milk is used.

In the manufacture of skimmed-milk powder, the milk is first separated, as soon as received, with a centrifugal separator. The skimmed milk is then pasteurized and passed on to the other steps of the drying process. For partly skimmed milk, whole milk and skimmed milk are mixed in the required proportions. For cream powder, the cream is standardized by regulating the separator or by mixing thick cream with a calculated amount of milk, either whole or skimmed.

In making milk powder for infant food, sucrose is seldom added to whole milk; it is more often added to partly skimmed milk,

before drying. From 1 to $1\frac{1}{2}$ per cent of the weight of the fresh milk is the usual proportion.

Drying Processes

Many drying processes have been invented. Twenty-one of these are mentioned and briefly described earlier in this chapter. They may be grouped into four classes. The first and oldest is the dough or mass drying method; the second, the drum or film method; the third class includes only one process, the flake process, in which the drying is done on a wire belt; the fourth, the spray or direct powdering method; and the fifth, the freezing method, the practicability of which has not been demonstrated.

There are three ways of carrying out the dough or mass drying method. In the first, the pan is open to the air, as in the Grimwade process. In the second, air is blown through the hot milk, as in the Campbell process. In the third, the dough is made in a vacuum pan, as in the Wimmer method.

There are also three ways of applying the drum or film drying method. In the first, the drum operates in the air under atmospheric pressure, as in the Just-Hatmaker, Gathman, and Gabler-Saliter processes. In the second, air is blown on to the surface of the drum carrying the milk film, as in the Kunick and Mignot-Pluney processes. The drum method may also be applied by enclosing the drum in a casing in which reduced pressure is maintained, as in the Passburg, Ekenberg, Gover and Buflovak processes.

There are two classes of spray or direct powdering methods, employing, respectively, pressure and centrifugal spraying. In the first, the milk is forced by a pressure pump through a spraying nozzle. Most spray processes, including the Stauff, McLachlan, Merrell-Soule, Gray, Rogers, and Benvenot and DeNeveu, belong to this class. The Dick process is a representative of the centrifugal spraying method.

The process of Lacompte and Lainville is the only one using the freezing method.

Selection of Processes.—In selecting a method for making powdered milk, the two things to consider are the quality of the powder produced and the simplicity and efficiency of the process.

The quality of the product is, of course, the more important consideration. Here let us recapitulate the essentials of first-quality milk powder. It must be perfectly soluble, in either warm or cold water, depositing no residue on standing. When the powder is placed on top of water in a test tube, it should go into solution immediately, without shaking or stirring. There should be no powder grains falling through the water without leaving milky trails. Under the microscope, the grains should lose their shape as soon as they meet the water; and, as the water runs past each grain, it should show as a stream carrying numerous fat globules, no curdy substance being left behind.

The solubility of powdered milk depends on many factors, as already discussed. Those depending on the process of manufacture are the temperatures to which milk and powder are subjected in the various processes of manufacture; the length of time the material is exposed to high temperature; the degree of concentration of the milk prior to drying; the moisture content of the resulting powder; the fat content of the powder; and the characteristics of the process itself. High temperature and long exposure to it hinder solubility. So do too high or too low concentration before drying. High moisture content reduces solubility on keeping. High percentage of fat, other conditions being the same, tends to hinder solubility. In general, dough-process powders are less soluble than those made by other methods, and the drum method is usually less effective in the production of soluble products than spray methods. Among drum processes, those that dry the milk at atmospheric pressure are less successful in making soluble powders than those that are evaporated in vacuum. Drier powders can be made by spray methods than by others.

The fat should be well emulsified before the milk is subjected to the drying process. On dissolving in water there should be no oily particles floating on the liquid. Such a product is very liable to become rancid or tallowy. Under the microscope the reconstituted milk should show comparatively even and small fat globules, not large ones, nor oily masses. The appearance of a cream line on reasonably long standing is permissible, or even desirable in a sense, but fat separation must not occur. Too quick appearance of a cream line in reconstituted milk is a sign of insolubility or of the separation of fat instead of cream. No cream line on

long standing is not always a sign that the milk powder is poor in fat, as in some processes the fat is probably homogenized before drying or in the spraying process. For infant feeding, homogenized powdered milk is desirable.

The factors affecting the condition of fat globules in milk powder are the temperatures to which the milk has been subjected, homogenization or non-homogenization, and the type of drying process. Fat which has been melted or crushed in drying causes the " oiling off " on reconstituting the powdered milk with hot water. Many drum-process powders oil off, while the fat in most spray powders is usually homogenized.

The reconstituted milk should have the flavor of ordinary fresh milk. A slight metallic tang is often noticed in the after taste. This probably comes from the metal surfaces with which the milk is in contact during manufacture. Such a tendency on the part of a drying apparatus is a disadvantage.

The factors affecting flavor are the temperature, moisture, contact with air, and the condition of the fat. High temperature may cause a cooked taste; high moisture, a musty or stale flavor. The air causes oxidation of fat, resulting in tallowy or rancid flavor. Crushed fat turns tallowy or rancid much sooner than that which has been emulsified. When milk is dried in contact with a hot surface, the scraping and grinding often crush the fat globules. Too thin a film of dried milk has more surface exposed per unit of volume, and thus its chances of tallowy deterioration are increased. From these standpoints drum methods are at a disadvantage in comparison with spray methods, provided the spray powders are not full of large air cores. Spongy powder grains made by some spray methods are poorer than larger and thicker flaky grains of drum powders.

The form of the powder grains has much to do with flavor. It has been shown how the form influences the ease of oxidation and this in turn affects flavor. Only the spray processes that spray under pressure and precondense the milk are superior to drum powders in this respect, as only these can produce the solid, small spherical grains which are so desirable.

The exposed surfaces in the grains of drum-dried milk may be minimized by precondensing the milk, thus increasing the thickness of the film. Higher drum speed also tends to make thicker

films, as the milk does not have time to flow back before drying begins. Thicker films necessitate an efficient drying system, in which reduced pressure is an important feature. With proper care, the improved vacuum drum driers will make a milk powder which keeps well.

The oxidation of packed powdered milk is not only influenced by the surface per unit volume of the grains, but is also very much influenced by the compactness of the packing. Spherical grains pack much more compactly than flaky ones. Kintaro brand, a whole-milk powder made by a spray process, was compared with Lactogen, a drum-process whole-milk powder. On being packed by tapping, the quantity of the former contained in a can of given size was more than one and one-half times as great as of the latter. In the former case, about 55 per cent of the space in the can is filled with milk-powder and 45 per cent with air; while in the other case, about 34 per cent is powder and 66 per cent air. This amounts to about 2.4 times as much air to a given weight of powder in one case as in the other.

Dahle and Palmer [45] filled a 2-oz. glass with 39 grams of Klim, (a high-pressure spray-process powder), and with only 20 grams each of Creamora A (a drum-process product) and of Creamon, (which is made by a centrifugal spray process), with moderate packing. This shows that the solid spherical powders occupy for a given weight only about half as much space as either drum-process flaky powders or spray-process spongy powders. Unless packed in vacuum containers, flaky and spongy powders are exposed to much greater chance of oxidation than those with solid spherical grains. It would appear from these considerations that a spray process using high pressure and precondensed milk will, other things being equal, produce a milk powder of better keeping quality than drum machines or centrifugal spraying processes.

Efficiency and Simplicity of Process.—None of the dough processes can be recommended for making a high-grade product. The better ones do well for such work as drying buttermilk for chicken feed.

Of the many drum processes, several make a powder which has good quality in most respects. The one possible advantage over

[45] Dahle, C. D., and Palmer, L. S., Jour. Dairy Sci., Vol. VII, p. 42.

the best spray methods lies in the lower temperature and shorter time of exposure to heat, with less danger of destruction of vitamins. The better drum processes involve apparatus which is rather complicated and expensive.

The various spray methods have been pretty fully discussed, and the best of them have been shown to possess the advantages of lower moisture, closer packing, and quicker solution. The author believes, from present indications, that progress toward perfect powdered milk lies along the road of improvement of apparatus for pressure spraying of precondensed milk.

Manufacturing

The general principles involved have all been discussed; care with regard to temperature and time of exposure; avoidance of changes in the milk constituents; production of grains without air cores and with small surface per unit volume. In drum powders the film should be reasonably thick and should not be ground too fine. In spray powders, the aim should be toward larger grains. Low moisture content (not above 2 per cent) should be secured. Packing with the least possible included air is an important feature.

Clarification.—The greatest precautions used in preparing milk for market are appropriate for the milk that is to be dried. The best milk may contain minute dirt particles, together with cells, living and dead, which pass through strainers. If these particles are not to be retained in the milk powder, they must be taken out with a clarifier. Many good clarifiers are made by the separator companies. In selecting a clarifier, it is better to choose one of greater capacity than that which seems to be necessary, so that the operation of the whole process may not be interrupted by accident to the clarifier. An extra machine is perhaps the best precaution.

The safest time for clarification is before pasteurization, as the heat may solubilize some of the impurities. If it is certain that no such impurities are present, pasteurizing first is an advantage, as the elimination of dirt and dead cells is then more complete. All methods of manufacture equally require clarified milk for the best product.

Pasteurization.—The supply milk should be pasteurized, to insure its freedom from tubercle bacilli and other hurtful microorganisms. In some processes, the high heat to which the milk is subjected in the drying makes pasteurization unnecessary. It is better to pasteurize first and then to reduce the temperature of manufacture, in the interest of solubility and general excellence of the product.

Vat pasteurization is preferable to the flash method, as the latter may destroy vitamin C and cause partial coagulation of albumin. Some of the calcium salts may be rendered insoluble also.

When precondensing is practiced, as is preferable in most cases, the preheater may take the place of vat pasteurizers. It is best to have several small heaters instead of one larger one, so that one may be filled and heated while another is being emptied by drawing the milk into the vacuum pan. The milk in the preheater is heated with constant stirring to 145° F., and this temperature maintained for twenty minutes. By using two or three heaters in turn, the process may thus be made continuous.

Homogenization of Milk.—For whole-milk powder, homogenization is, in general, beneficial. It helps the keeping quality and prevents the fat from " oiling off " on reconstitution with water. With certain spray processes, however, such as the Merrell-Soule, the spraying of milk through a nozzle under high pressure takes the place of any preliminary homogenization. For dough and drum processes, it is desirable, as the fat oils off badly otherwise, on dissolving.

Homogenization is best done immediately after pasteurization at the pasteurization tempertaure. At a lower temperature, homogenization of the fat is not complete. It may also be done after precondensing. In such a case, the degree of condensation and the pressure of the homogenizer must be carefully regulated. Otherwise, the resulting powder may become more insoluble, as the homogenizing may disturb the colloidal dispersion of the casein. All the precautions mentioned in connection with homogenizing fresh milk and milk for evaporated milk must be rigidly observed.

Precondensing.—This operation is not invariably carried out, but it is recommended for all processes. In drum processes it

makes possible a thicker film and more rapid drying. In spray methods it makes the danger of spongy grains less. The homogenization of fat due to pressure spraying is made greater by precondensing. Precondensing helps to secure long keeping in powders made by any process.

The proper degree of concentration is between one-half and one-fourth of the original milk. If the milk is reduced to less than one-fourth of its volume before being put into the drier, it is apt to be less soluble, as the casein becomes very unstable. If after being condensed, the milk is kept for some time at the temperature of the vacuum pan, it may gradually coagulate to very soft, friable curd. From such milk, good soluble milk powder cannot be made.

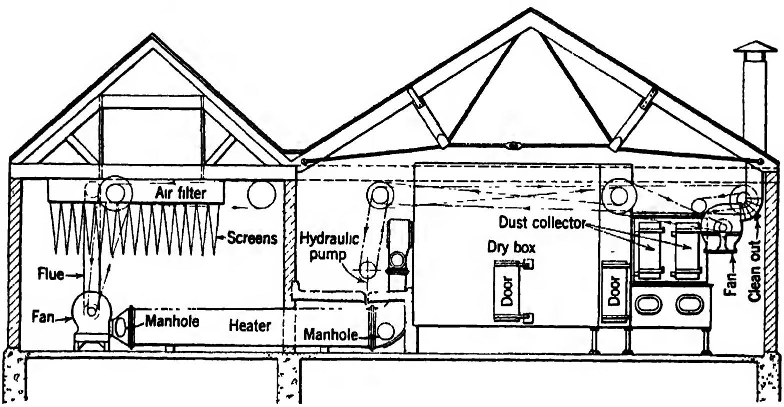
In operating the vacuum pan for precondensing milk for manufacture of milk powder, all the precautions mentioned in connection with the manufacture of unsweetened condensed milk must be observed, except that the product must not be superheated. The vacuum should not be permitted to fall below 25 ins., and the temperature of the milk in the pan should not exceed 130° F. if the best results are to be obtained. Steam pressure should be applied very cautiously to jacket and coils, avoiding any bare heating surfaces, which may cause more insoluble matter in the powdered milk. Unless the milk-condensing machine is of the continuous sort, the steam should be shut off some time before the operation of the vacuum pan is entirely stopped, to give ample time to adjust the temperature of the heating appliances to the temperature of the milk in the pan. Otherwise, the milk may coagulate at the heating surfaces before it is drawn out of the pan.

The ordinary vacuum pan, such as is used for condensed milk and evaporated milk, is satisfactory for precondensing, but a continuous apparatus is desirable. For operating a drier to its full capacity, a continuous precondenser is almost essential. The only disadvantage of the continuous concentrator is the difficulty of securing a uniform product. Careful adjustment of vacuum and steam pressure, with proper standardization of the milk before condensing, and uniform feeding of milk to the concentrator, ought to minimize this disadvantage.

Drying.—This is the most important part of the process of making milk powder. If a really good product is to be made, either a drum or a spray process must be used. Without preju-

dice to other processes, the Buflovak system may be recommended if a drum process is to be chosen, or the Merrell-Soule if a spray method is preferred. There is no reason why, with careful manipulation, milk powder of very good quality may not be made with other processes also.

A first consideration in the drying process is to protect the milk from long exposure to high temperature. When a drum drier is used, it should be operated under high vacuum to reduce the evaporating temperature; the steam which heats the drums should be at the lowest pressure consistent with rapid and complete drying; and the speed of the drum should be such as to keep the



Courtesy of the Merrell-Soule Company

Fig. 72.—Merrell-Soule Milk Drier.

milk in contact with it as short a time as possible. When the drum is operating in a chamber at high vacuum, one may be misled into supposing that the temperature of the milk is very low. But the milk is in contact with a heated drum, and, at least by the end of the drying process, it acquires a temperature nearly as high as that of the drum, which may be much higher than that of the chamber.

When a spray drier is used, it is best to use a high-pressure nozzle, and the pressure of the pump and the size of the spray disk should be so regulated as to get a proper distribution of spray in the drying chamber. In this process, the purity and dryness of the air blown in are of the highest importance. The air is purified by passing through a filter of cloth or of oiled steel shavings. In

some processes, the air is used without filtration, but this is not the way to make a good milk powder. Any dust in the air will be passed on to the powdered milk. The air filter is usually placed at the entrance, and the filtered air is blown into the air drier by a powerful blower.

Different processes use different heaters. A tubular, boiler-like heater is generally used, steam being the heating agency, and its pressure being regulated with the aid of a gauge. The air passes through a number of tubes, surrounded by steam. The disadvantage of this heater is that the tubes are liable to rust, and the flakes of rust may be blown into the drying chamber and incorporated with the milk powder. When the heater is left unused for any length of time, the tubes should be well cleaned and blown out before use. It would be well to have a filter between the heater and the drier, but such a plan involves practical difficulties with present forms of apparatus.

Before beginning the drying of milk, the drying chamber should be well cleaned and the dust collector properly adjusted. Then all doors and powder-discharge holes should be closed, the heated air blown in, and the dust collector operated. When the temperature of the drying chamber reaches 190° to 200° F., the pressure pump is started, and the spray valve opened when the proper pressure is reached, spraying being continued at a uniform pressure. The pressure of the spray pump may vary with different processes, but for any one process it should be uniform.

For successful drying, the supply of dry air should be plentiful. The more abundant and the drier the supply of air, the lower its temperature may be; and it is desirable to have as low a temperature as is consistent with rapid and complete drying. The temperature of the drying chamber will drop after the spraying is begun, heat being used up in the process of evaporating water from the milk. If the temperature goes too low, the drying is not satisfactory. Manufacturers of drying machines recommend that the temperature be not allowed to fall below 170° F. With proper precondensing and a very full flow of very dry air, it is possible to work at a temperature somewhat below 170° and get a powder whose moisture content is below 1 per cent.

Improvements in spray-drying systems should bring the temperature of the chamber to 150° F. or even less, and should

eliminate the oxygen from the drying air. A great disadvantage of the spray system of drying milk is the fact that it is dried in a current of air, consisting partly of active hot oxygen.

Grinding and Sieving.—Dough-process milk must be ground and sieved, the coarser parts being reground or rejected, to be used as chicken feed or made into calf meal. Drum process powders require little grinding, and should not be ground too fine, for the reasons given above. The fineness should be just sufficient for convenient packing. Spray-process milk powder is usually sieved to eliminate any lumps or crusts. If the condition of the spray powder is sufficiently uniform, sieving may be omitted.

Packing.—The packing should be done as soon as possible after the drying is completed. Any delay invites absorption of moisture from the air and bacterial contamination. If, for any reason, the packing cannot be done at once, the powder should be kept in a clean, dry room. Milk powder with 1 per cent of moisture or less will absorb moisture at room temperature from any except artificially dried air.

Milk powder is either packed in bulk or put into small tin cans from 8 oz. to 5 lbs. capacity, 1 lb. being the standard. The usual bulk package is the barrel of 200 lbs. The tins are placed on the market for family use and the barrels go into commercial channels. The bulk powder is commonly used in a comparatively short time, while the cans may lie on the shelves of stores for a long time. For this reason the care taken in packing the cans must be great. Hermetically sealed cans are important for good keeping, as has been shown on an earlier page. Vacuum packing and packing with inert gases are effective ways of checking deterioration. If these methods are not used, close packing, so as to leave as little air as possible in the can, is very desirable.

As the forms and sizes of powder grains differ widely in different makes of milk powder, the sizes of cans vary accordingly. The following table gives measurements of cans of various brands found in the Japanese market.

It will be observed that the drum-process powders occupy much more space than the spray-process packages of the same weight of powder. The smallest ½ lb. package is that of a dough-process product, which is accounted for by the fact that this powder has nearly 50 per cent sucrose. The Glaxo can is the

SIZES OF POWDERED-MILK CONTAINERS

Brand	Net Weight of Powder, Pounds	Diameter, Cm.	Height, Cm.	Capacity, Cc.	Remarks
Lactogen	1	10.5	11.15	965.0	Drum process
Lactogen	½	8.6	8.20	476.1	Drum process
Glaxo	½	8.3	11.15	602.9	Drum process
Morinaga	½	8.5	8.20	567.1	Drum process
Klim	1	8.4	12.50	692.4	Spray process
Bonalac	1	10.0	11.55	906.7	Spray process
Bonalac	½	8.6	8.50	493.5	Spray process
Kintaro	1	8.4	12.00	664.7	Spray process
Kintaro	½	8 4	6.70	371.1	Spray process
Darigold	½	6.4	9.20	294.8	Spray process
Oshidori	½	6.4	8.50	274.3	Dough process

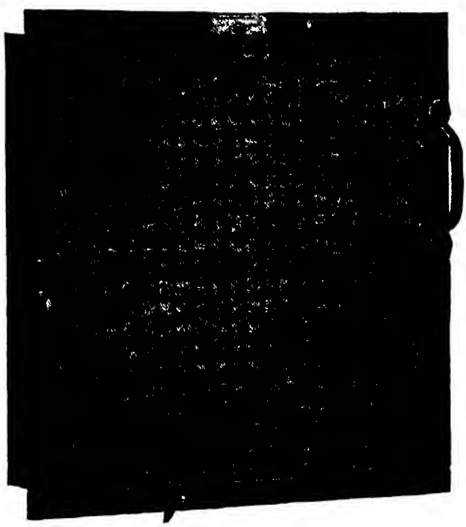


FIG. 73.—THE REED AIR FILTER.

This may be used in filtering air for the spray milk-drying process.

largest of the drum powders, largely because the powder is put into a paper bag and this in turn into the can. The large amount

of unnecessary air thus introduced may account, at least in part, for the very tallowy flavor of the powder, which is characteristic of this product as found in the Japanese market. The Bonalac packages were not full, and the grains were spongy, all of which helps to account for the larger container and the poor quality of the powder. The Darigold can was the smallest of the spray-process brands. This is due to the fact that this brand is a skimmed-milk product.

Possible Improvements in the Spray-drying System

Some of the spray processes are nearly perfect. Still, there is one very important point at which improvement would be desir-

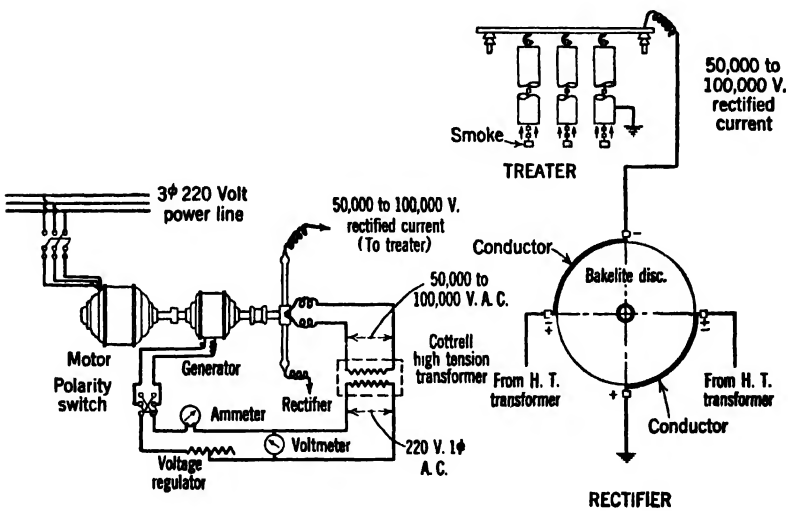
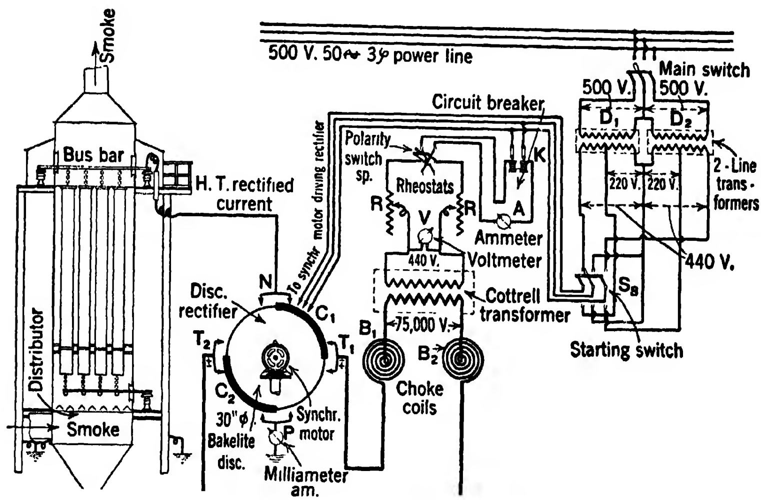


Fig. 74.—Demonstrative Diagram for Cottrell Electrical Precipitation Process.

able. It is the heated air used for drying the spray. Another thing that might well be improved is the efficiency of the method of collecting the powder from the current of air. The recovery of the powder should be more nearly complete than it is at present.

The present method of heating the air blown into the drying chamber, by means of steam, is expensive and wasteful. Besides, the heating of the air renders the oxygen in it very active, so as to

increase its harmful effects on the milk constituents. To escape these difficulties, it has been proposed to use, as the current of drying gas, the escaping gases from a furnace in which coke is burning. A good coke is almost free from hydrogen, so that the gases of combustion are free from water vapor. Nearly all the oxygen may be consumed out of the air by careful regulation. The gas contains a good deal of dust, which must be filtered out, and it is too hot for the purpose. The extra heat can be utilized by passing the gases around boilers for the production of steam, thus cooling them nearly to the desired temperature.



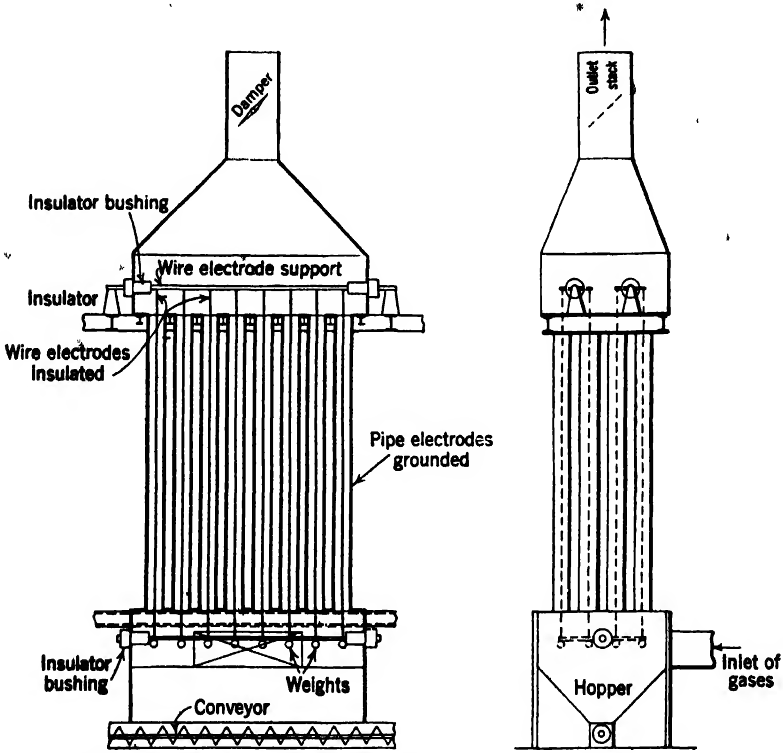
Courtesy of Hidachi Motor and Machine Co

FIG. 75.—WIRING DIAGRAM OF COTTRELL PROCESS OF ELECTRICAL DUST COLLECTION, INSTALLED AT KINZOKU KOGYO KENKYUSHO.

Purification of the gases from dust is less easy than reducing the temperature. Coke is nearly all carbon, so that the stream of gases consists mostly of carbon dioxide and the nitrogen of the air. But along with the stream of hot gas goes a quantity of dust, made up from the ash, which may be as much as 10 per cent of the coke. Coke also contains some sulphur, which is undesirable. It would be advisable to select brands in which both ash and sulphur are low. Much of the dust may be removed by

passing the gas through air filters before it enters the drying chamber. Such filtration, however, presents serious difficulties if it is to be made complete.

It is believed that the Cottrell process of dust collection may serve for complete purification of the gases from dust particles.



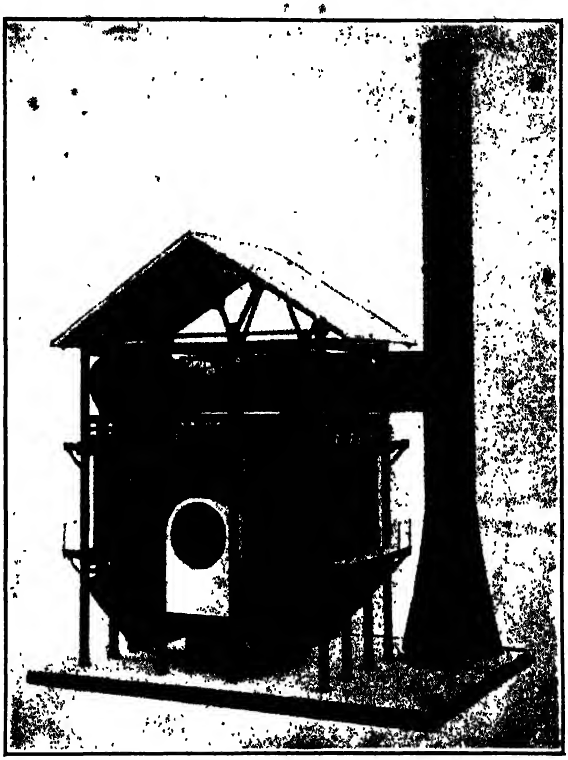
Courtesy of Hidachi Motor and Machine Co.

FIG. 76.—MULTIPLE PIPE TREATER, COTTRELL PROCESS OF ELECTRICAL DUST COLLECTION

This process was designed for purifying gas currents from smoke and fine dust. It depends on the attraction of highly charged electrodes, and is successfully used in cement factories, smelters, and the like.

The accompanying diagram shows the method. Alternating current at 220 volts is stepped up to from 50,000 to 100,000 volts

by means of a transformer, and then passed through a rectifier. The rectified current is then led to the treater where the dust or smoke is collected. Each unit of the treater consists of a metallic cylinder connected to one pole, and a chain, hanging in the middle of the cylinder, connected to the other pole. As the stream of



Courtesy of Hidachi Motor and Machine Co.

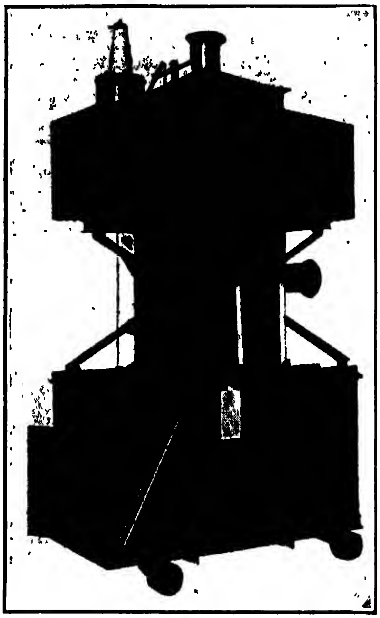
FIG. 77.—COTTRELL TREATER CONNECTED TO SMOKESTACK.

gases passes through the cylinders, the particles of dust are caught by the electrical attraction of the chain or cylinder.

Many experiments were tried with this apparatus at smelters and cement factories. Hirota and Shiga[46] reported the results of experiments at the Ashio and other smelters. The volume of gases handled at Ashio was estimated at more than 150,000

[46] Hirota, K., and Shiga, K., Cottrell Electrical Precipitation Process in Japan.

cu. ft. per minute. The amount of dust collected varied from 6 to 10 tons in twenty-four hours. The efficiency of precipitation seemed to depend on the nature of the furnace charge and the moisture and temperature of the gases treated. When the conditions were very favorable it ran as high as 98 per cent. When the conditions were bad, the charging voltage was raised to 80,000 volts, and the precipitation was very satisfactory. The materials



Courtesy of the Hidachi Motor and Machine Co.

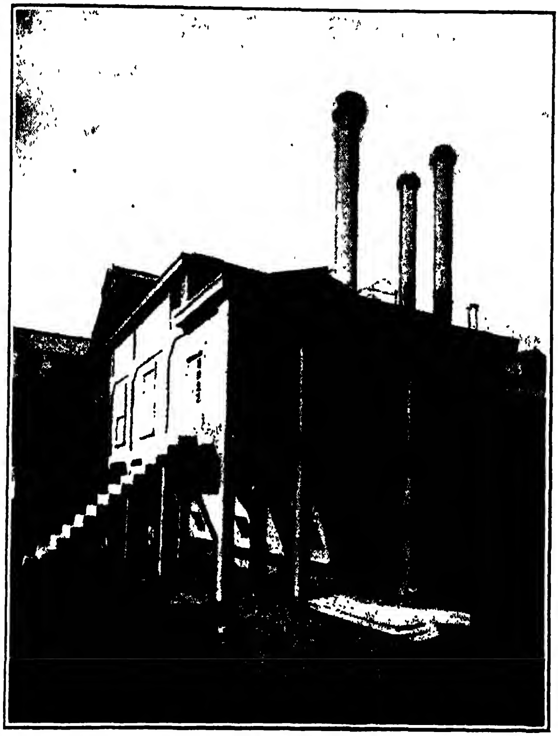
FIG. 78.—PORTABLE COTTRELL TREATER, INSTALLED AT THE KYUSHU IMPERIAL UNIVERSITY.

precipitated included not only the poisonous dust, such as arsenic trioxide, but even the water.

Judging from the character of the machine and the materials collected, the Cottrell process could be applied to the purification of gases of combustion from coke, so that they could be used in milk drying. It has been claimed also that this process may be used for collecting the milk powder from the escaping current of moisture-laden air. The fact that Hirota and Shiga found that

moisture is collected by the apparatus makes it unlikely that dry milk powder could be separated from moist air.

As to any effect of the process on milk, an experiment was tried to test whether or not it injured milk powder in any way.



Courtesy of Hidachi Motor and Machine Co.

FIG. 79.—A COTTRELL TREATER IN ACTUAL USE.

Dry-milk powder was blown into the apparatus. It was collected perfectly, and analysis showed no change in constituents except an increase in moisture from 1.04 to 1.95 per cent. The bacterial content, as before noted, was not affected.

APPENDICES

APPENDIX A

FORMULÆ RELATING TO COOLING

If W_w is the weight of warm liquid, having a specific heat d_w, and the cooling liquid has a specific heat d_c and weight W_c, the warm liquid being cooled from a temperature t_{wa} to t_{we}, while the cooling liquid rises from t_{ca} to t_{ce}, the quantity of heat transferred, C, will be the product of the weight of either liquid by its specific heat, multiplied by the change of temperature. The formula is, therefore, $C = W_w d_w (t_{wa} - t_{we}) = W_c d_c (t_{ce} - t_{ca})$. In the case of milk and water, the specific heats are not very different, so that we may say that the weight of warm milk multiplied by its fall in temperature very nearly equals the weight of cooling water multiplied by its rise in temperature.

The area of the surface between the liquids must be greater for a greater amount of heat transferred, but is inversely proportional to the mean temperature difference between the liquids, and to the coefficient of transmission. That is, S being the area,

$$S = \frac{C}{k_c \theta_m} = \frac{W_w d_w (t_{wa} - t_{we})}{k_c \theta_m},$$

where k_c is the coefficient of transmission of heat, and θ_m is the mean temperature difference.

The coefficient of transmission of heat between two liquids may be found by experiment for any given set of conditions. Mollier and Joule experimented with copper and brass separating walls, and derived the following equation:

$$K_c = \frac{300}{\dfrac{1}{1 + 6\sqrt{v_{f1}}} + \dfrac{1}{1 + 6\sqrt{v_{f2}}}}.$$

In this formula, v_{f1} and v_{f2} are the velocities of the two liquids in meters per second. The thickness of the diaphragm is neglected, because, for the two kinds of metal mentioned, the conductivity of thin walls is high. Smoothness of the surfaces is important, and " furring " due to material sticking to the surfaces decreases the rate of transmission very much. It is probable that if the numerator of the formula be altered from 300 to 200 it will apply fairly well for average conditions. It will be observed that this formula indicates that the coefficient of heat transmission depends on the velocity of flow of both liquids, and an increase in these velocities increases the rate of heat exchange between the warm liquid and the cooling liquid.

APPENDIX B

PRINCIPLES OF HEATING

Water is often heated by having saturated steam passed into it. Other liquids may be heated in the same way, and this method is sometimes employed in heating milk in condensed-milk factories. It is an efficient method of heating, but has disadvantages for heating milk. The water added to the milk by condensation of the steam must again be evaporated. The latent heat of steam is about 537 calories, or, in the English system, about 965 B.T.U. One pound of steam in condensing, therefore, adds to the milk 965 B.T.U., and if the milk is at 50°, the pound of water of condensation, in cooling to 50° F., gives up 212 − 50, or 162 B.T.U. more, a total of 1127 B.T.U. If we assume the specific heat of milk to be the same as that of water, which is very nearly true, the amount of steam required to heat 5000 lbs. of milk at 50° F. to 200° F. will be $\frac{5{,}000 \times (200 - 50)}{965 + 212 - 200} = 767$ lbs. That is to say, the weight of the milk is increased by 767 lbs., or more than 15 per cent.

More frequently the heating is done by means of steam coils. The experiments of Ser indicate that in the case of water with horizontal tubes of 10 mm. bore and 314 mm. long, the transference of heat increases approximately as the cube root of the velocity of the water. Hagemann showed that the quantity of heat transmitted increases not only with the velocity of the liquid but also with the temperature at which the transfer takes place. From Hagemann's data, Mollier deduced the following equation for the value of the coefficient of transmission of heat, designated as k_c:

$$k_c = 50 + \left\{1000 + 10\left(t_d + \frac{t_{fa} + t_{fe}}{2}\right)\right\}\sqrt{V_f},$$

where t_d is the temperature of the steam, t_{fa} and t_{fe} the initial and final temperatures of the liquid, and V_f the velocity of the liquid. This formula assumes Centigrade temperatures and meters per second.

Nichol's experiments indicate that a greater amount of heat is transferred when the tubes are horizontal than when they are vertical, the ratio being about 3 : 2.

Hausbrand explains the more rapid transfer at higher temperatures by the greater mobility of the liquid, which permits more rapid circulation. The greater coefficient in the case of the horizontal tube is explained by the quickness with which the heated liquid in that case leaves the surface of the tube, while it must rise for some time in contact with the hot surface when the tube is vertical.

In heating liquids by means of a steam-jacketed vessel, when the liquid is cold, the pressure of steam in the jacket falls rapidly with distance from the entrance, and may be actually zero in the part of the jacket farthest from the steam entrance. As the liquid becomes warmer, the steam pressure rises. If the mean temperature difference between the liquid and the steam be considered as one-half of the difference between the initial temperature of the liquid and that of the steam, and if the coefficient of transmission be taken as 1400 (allowing for incrustation), Hausbrand calculates the quantities of heat transmitted from the steam to the liquid to be within the limits of the following formulæ:

$$C = 1400S_m = 700S(t_d - t_f) \text{ up to } C = 1800\ S_m = 900\ S(t_d - t_f).$$

In these, t_d is the Centigrade temperature of the steam, t_f the temperature of the liquid at the beginning, and S the surface in square meters.

If the liquid to be heated is more viscous than water, the efficiency will be less. The value of the factors to be substituted in the above equations in the case of milk must be determined by experiment. The viscosity of milk varies greatly with temperature, as has already been pointed out. An average value will be nearly twice that of water; that is, its mobility is about half that of water. Making this change in the first equation above,

$$C = 350S(t_d - t_f).$$

The heating surface may be calculated from this formula. Converting to the English system and expressing S in terms of the other factors, we have

$$S = \frac{C}{72(t_d - t_f)}.$$

Suppose 6000 lbs. of milk are to be heated in one hour from 50° F. to 200° F., with steam at 230° F. in the jacket. What must be the area of the heating surface, there being no stirrer? Here C is 150 × 6000 or 900,000, for the numerator in the expression above. The value resulting

is 69 sq. ft. As has been stated, a jacketed pan without a stirrer is not practicable because the milk burns fast to the pan.

Stirring not only prevents burning, but greatly increases the transmission of heat, in proportion to the square root of the velocity with which the milk is moved over the surface, as has been shown. Suppose a stirrer is used, giving the milk an average velocity of 3 ft. per second. The heating surface may be calculated from the equation given in Appendix A:

$$k_e = \frac{200}{\dfrac{1}{1 + 6\sqrt{v_{f1}}} + \dfrac{1}{1 + 6\sqrt{v_{f2}}}}.$$

If the heating medium is steam, $\dfrac{1}{1 + 6\sqrt{v_{f2}}}$ is approximately $\dfrac{1}{10{,}000}$. Then, transferring to the English system, and calling the constant k_{ae}, placing the value of v_{f1} at 3 ft. per second, the resulting value of k_e is 997. Assuming the mean temperature difference as half the difference between that of the cold milk and that of the steam, we get, in the equation for S, the value 10 sq. ft. instead of 69.

APPENDIX C

The Boiling Temperatures of Water and Sugared Milk under Different Pressures

Absolute Pressure, Lbs. per Sq. In.	Vacuum Ins. Hg Column	Vacuum Mm. Hg Column	Boiling Temperatures of Water °F.	Boiling Temperatures of Water °C.	Boiling Temperatures of Sugared Milk °F.	Boiling Temperatures of Sugared Milk °C.
14.720	0.00	0	212.00	100.00	212.90	100.50
14.010	1.42	36	209.55	98.50	210 45	99.00
13.150	3.45	88	205.87	96.80	206.77	97.30
12.015	5.49	139	201.96	94.30	202.86	94.80
11.020	7.52	191	197.75	91.90	198.66	92.40
10.020	9.56	243	193.22	89.50	194.12	90.00
9.020	11.60	295	188.27	86.75	189.17	87.25
8.024	13.63	346	182.86	83.70	183.76	84.20
7.024	15.67	398	176.85	80.50	177.75	81 00
6.024	17.70	450	170.06	76.80	170.96	77.30
5.029	19.74	502	162 28	72.50	163.18	73.00
4.029	21 78	553	153 01	67 20	153.91	67 70
3.034	23.81	605	141.52	60.80	142.42	61.30
2.034	25.85	657	126.15	52 30	127.05	52.80
1.040	27.88	708	101 83	38.70	102 73	39.20
.980	28.00	712	100.00	37.80	100.90	38.30
.735	28.50	724	90.00	32 20	90.90	32.70
.544	28.89	734	80.00	26 70	80.90	27.20
.402	29.18	741	70.00	21.10	70.90	21.60
.294	29.40	747	60.00	15.60	60.90	16.10
.216	29.56	751	50.00	10.00	50.90	10.50
.162	29.67	754	40.00	4.40	40.90	4.90
.127	29.74	756	32.00	0.00	32.90	0.50

APPENDIX D

RELATION OF ATMOSPHERIC PRESSURE, BAROMETER READING, ALTITUDE ABOVE SEA LEVEL, AND EQUIVALENT VACUUM AS IT APPEARS ON GAUGE IN INCHES

Barometer Reading, Ins. of Hg	Atmospheric Pressure, Lbs. per Sq. In.	Altitude above Sea Level, Ft.	Equivalent Vacuum as it Appears on Gauge, Ins.	
30 0	14 72	0	25.0	28.0
29.7	14.60	264	24 7	27.7
29 5	14.47	441	24.5	27.5
29 2	14.35	710	24.2	27.2
29.0	14 23	890	24 0	27.0
28 7	14 11	1,163	23 7	26.7
28.5	13 98	1,347	23 5	26.5
28 2	13.86	1,625	23.2	26.2
28.0	13 74	1,812	23 0	26.0
27.5	13.50	2,285	22 5	25.5
27 0	13.26	2,767	22.0	25.0
26.5	13.02	3,257	21 5	24.5
26.0	12.77	3,758	21.0	24.0
25.5	12.53	4,268	20.5	23.5
25.0	12.27	4,787	20 0	23.0
24.5	12.03	5,318	19.5	22.5
24.0	11.78	5,859	19 0	22.0
23.5	11.54	6,412	18.5	21.5
23.0	11.30	6,977	18.0	21.0
22.5	11.05	7,554	17.5	20.5
22.0	10.80	8,144	17.0	20.0
21.5	10.56	8,747	16.5	19.5
21.0	10.31	9,366	16.0	19.0
20.0	9.81	10,645	15.0	18.0

APPENDIX E

TRANSFERENCE OF HEAT IN VACUO

Because of the greater temperature difference, the rate of transference of heat from the steam to the liquid in a vacuum-pan is greater than at atmospheric pressure. The following arbitrary formula is approximately correct:

$$S = \frac{C}{1000\theta_m}, \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (1)$$

where C is the amount of heat transferred (calories), S is the area of the heating surface in square meters, and θ_m is the mean temperature difference in Centigrade degrees. In the case of a jacketed heater, where part of the heat is lost through the wall of the jacket, the following formulæ may be used, where k is a constant whose value varies with the sort of liquid:

$$C = S\theta_m k; \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (2)$$

or

$$S = \frac{C}{\theta_m k}. \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (3)$$

Hausbrand gives values for k in this case as follows: for water, 1600; for thin liquids, 1200; for thick liquids, 900 to 500.

To which of these classes milk belongs is a question. At the first stage of condensing it may be regarded as a thin liquid, but later it is a thick one. In order to calculate the necessary area of heating surface for a vacuum pan, it will be well to use the lowest of these values, so as to make the surface large enough for the most difficult case. Assume 500 for k, and the above equation for S becomes

$$S = \frac{C}{500\theta_m}. \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (4)$$

If these equations be written for English units, Fahrenheit degrees, square feet, and British Thermal Units, (1) becomes

$$S = \frac{C}{200\theta_m} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

for pipes immersed in the milk. and (4) becomes

$$S = \frac{C}{100\theta_m}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

for the steam jacket. These arbitrary equations are derived from experience.

Suppose it is required to estimate the area of coils to be placed in a vacuum pan which is to be used to condense 20,000 lbs. of milk daily, in one batch. Exhaust steam is to be used in the jacket and live steam in the coils. The diameter of the pan may be 7 ft. The depth of jacket may be 18 ins. The temperature of the milk drawn in is to be 200° F., and the vacuum maintained is to be 26 ins. on the average. It is required that the operation of the pan should not take longer than three hours. Then the calculation may be as follows:

The total amount of water to be evaporated under average conditions will be

$$20{,}000 + \frac{20{,}000 \times 16}{100} - \frac{20{,}000 \times 36.49}{100} = 15{,}902 \text{ lbs.}$$

If this is to be evaporated in three hours, the amount of water to be evaporated per hour will be $\frac{15{,}902}{3} = 5{,}301$ lbs.

Since the diameter and the depth of the jacket are known, the heating surface may be calculated as follows:

$$0.785 \times (7^2 + 4 \times 1.5^2) = 45.5 \text{ sq. ft.}$$

The heating surface of the jacket is 45.5 sq. ft. Since exhaust steam is to be utilized in the jacket, its temperature may be considered as 230° F. If the vacuum is kept at about 26 ins., the boiling temperature of the milk will be about 125° F. The mean temperature difference is approximately 52.5° F. Therefore, the quantity of heat that may be transmitted through the jacket per hour will be, from equation (6),

$$C = 100 \times 52.5 \times 45.5 = 238{,}875 \text{ B.T.U.}$$

Since the temperature of the milk when drawn in is 200° F., and the boiling temperature of the milk in the pan is 125° F., the milk itself

supplies heat for self-evaporation, the quantity per hour being approximately

$$\frac{20,000}{3} \times (200 - 125) = 500,000 \text{ B.T.U.}$$

The total heat units that the steam jacket and hot milk supply will then be

$$238,875 + 500,000 = 738,875 \text{ B.T.U.}$$

Here the heat of the sugar is not considered, because, in practice, heat is lost by radiation from the body of the pan and the milk retains a little higher temperature than the theoretical boiling temperature, especially in the later stages of evaporation.

The total heat of evaporation required per hour will be

$$5,301 \times 965.7 = 5,119,175 \text{ B.T.U.}$$

The amount of heat to be supplied by the coils will be the difference between the total quantity of heat required and that supplied by the jacket and by the milk itself, or

$$5,119,176 - 738,875 = 4,380,301 \text{ B.T.U.}$$

The heating surface of the coils may then be calculated from equation (5), as follows:

$$S = \frac{4,380,301}{200 \times 62.5} = 350 \text{ sq. ft.}$$

In this calculation the steam pressure in the coils is considered as 15 lbs. on the average. In practice, an average pressure of 20 lbs. may safely be applied. Then the heating surface of the coils becomes

$$S = \frac{4,380,301}{200 \times 67} = 326 \text{ sq. ft.}$$

The total surface of the coils required is, therefore, approximately 326 sq. ft. If the coils are to be made in four sections, the diameter of the copper pipe of the lowest section being 4 ins., and that of the rest being 5 ins., and provided the lengths of the coils of all sections are to be the same, the length of the pipe for each section will be

$$\frac{4}{12}\pi L + \frac{5}{12}\pi 3L = 326$$

$$L = \frac{326 \times 12}{19\pi} = 66 \text{ ft.}$$

Therefore, the length of the coils of each section must be 66 ft. This is rather long, and, in practice, it will be very difficult to place the coils conveniently. The difficulty in this case is that the time requirement is too short for the amount of milk. Four to five hours will be the logical allowance for this amount of milk, or the milk may be condensed in two batches. If it is to be condensed in four hours, the surface of the heating coils required will be

$$S = \frac{3.225.816}{200 \times 67} = 241 \text{ sq. ft.}$$

$$L = \frac{241 \times 12}{19\pi} = 48 \text{ ft.}$$

This length is practicable for the coils of a 7-ft. pan.

The coefficient of transmission of heat differs with the length and the diameter of the coils, decreasing as the length and diameter increase, in proportion to their square root. Hausbrand gives, from his experiments and those of Long, Morison, and Jelinek, an empirical equation for the coefficient of transmission of heat to boiling water from saturated steam, as follows:

$$k = \frac{1900}{\sqrt{dl}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The coils are more efficient if they are made in a greater number of sections with smaller pipes. But the smaller pipes introduce other difficulties, which may more than balance their greater heating efficiency.

Experience shows that in a vacuum evaporator at about 26 ins. of vacuum, there are evaporated in one hour, per square foot of heating surface, the following amounts of water from specified liquids:

EVAPORATION OF WATER PER SQUARE FOOT OF HEATING SURFACE UNDER A VACUUM OF 26 INS.

	Pounds
With exhaust steam at 230° F.:	
From water	220–242
From thin liquid	132–154
From thick liquid	66– 99
With high pressure steam at 266° F.:	
From water	301–385
From thin liquid	176–220
From thick liquid	88–110

APPENDIX F

The Coefficient of Transmission of Heat in Calories for 1 Hour, 1° C. and 1 Square Meter, between Steam and Boiling Water, for Copper Heating Coils of Various Sizes

ameter, Mm.	Length of Tube, M. 4	6	8	10	15	20	30
30	5490	4510	3875	3408	2835	2455	2004
35	4900	3900	3500	3200	2640	2270	1850
40	4750	3875	3363	3007	2455	2110	1743
45	4510	3600	3165	2835	2300	2004	1610
50	4253	3408	3007	2687	2190	1900	1558
60	3875	3170	2740	2455	2004	1743	1415
70	3600	2930	2540	2270	1890	1610	1310
80	3363	2740	2375	2125	1711	1490	1225
90	3170	2580	2245	2004	1610	1410	1157
100	3007	2455	2135	1900	1558	1364	1100
125	2687	2191	1820	1700	1390	1202	982
150	2455	2004	1743	1555	1266	1100	905

In the above table, the thickness of the metal is taken at about 2 mm. For wrought-iron pipe of about 3.5 to 4 mm. thickness, the coefficient of transmission of heat is said to be about 75 per cent of that for copper; and for cast-iron pipe of about 10 mm. thickness, it is about one-half of that for copper.

The coefficient of transmission of heat given in the above table is in the metric system. If it is to be converted into the English system the number must be divided by the factor 4.88; the results will then be the quantity of heat, in British Thermal Units, transmitted per hour per degree Fahrenheit temperature difference per square foot for the dimensions given in the table. The dimensions of the tube are given in the table in millimeters and meters. Therefore, they must also be converted into English measurements in order to make the table useful for the English system. The coefficient of transmission of heat per hour per degree Fahrenheit temperature difference per square foot may be calculated from the following equation:

$$k = \frac{4424}{\sqrt{dl}}, \qquad (8)$$

where d is the diameter in inches and l is the length of pipe in feet. The value of k, here, will be in British Thermal Units.

The following table gives the actual results obtained by various experimenters on the transmission of heat from steam to water through coils.

TRANSMISSION OF HEAT FROM STEAM TO WATER

Author	Character of Surface	Steam Condensed per Square Foot per 1° F. Dif. per Hour		Heat Transmitted per Square Foot per 1° F. Dif. per Hour		Remarks
		Heating, Pounds	Evaporating, Pounds	Heating, B.T.U.	Evaporating, B.T.U.	
Laurens...	Copper coils	0.292	0.981	315	974	
Laurens...	2 copper coils	....	1.200	....	1120	
Havrez....	Copper coil	0.268	1.260	280	1200	
Oerkins...	Iron coil	....	0.240	....	215	Steam p. = 100
Oerkins...	Iron coil	... ...	0.220	....	208.2	Steam p. = 10
Box.......	Iron tube	0.235	....	230		
Box.......	Iron tube	0.196	....	207		
Box.......	Iron tube	0.206	....	210		

APPENDIX G

QUANTITY OF COOLING WATER FOR CONDENSER

If W represents the number of pounds of cooling water passing through the condenser, entering at temperature t_1, and leaving, after condensing the vapor and mixing with the water of condensation, at temperature t_2, the amount of heat absorbed will be $W(t_2 - t_1)$; and if the temperatures are in the Fahrenheit scale, these heat units will be British Thermal Units. Each pound of vapor condensed gives up its latent heat of vaporization and also sensible heat corresponding to the difference between the boiling temperature in the vacuum pan and the temperature of the escaping water. The number of heat units given up by a pound of vapor in condensing is not the same at all temperatures, being slightly greater at lower boiling temperatures; but no serious error is introduced by using the value of the heat of vaporization at 212° F., which is nearly 966 B.T.U. If the temperature of the pan is t_3, the temperature of the water of condensation falls $t_3 - t_2$ degrees. If D is the quantity of vapor condensed, in pounds, the heat given out is $D(966 + t_3 - t_2)$. The heat taken up by the cooling water and that given up by the vapor are equal, if we neglect minor factors; we therefore have the following equation:

$$W(t_2 - t_1) = D(966 + t_3 - t_2).$$

Suppose we have the problem discussed in Appendix E, where 20,000 lbs. of milk are condensed daily at an average vacuum of 26 ins. The amount of water to be evaporated is 15,900 lbs. If the condenser water has a temperature of 60° F., and the waste water is to be within 10 degrees of the boiling temperature in the pan, the rise of the cooling water will be about 55 degrees, since the boiling temperature at 26 ins. of vacuum is about 125° F. Putting these values into the above equation, we have $W \times 55 = 15{,}900(966 + 10)$, or $W =$ about 280,000 lbs.

If the available supply is not sufficient, and the cooling water has to be used over and over, the temperature of the entering water will be much higher than 60°. Air cooling will leave it warmer than the air, and in summer its temperature will be perhaps 80°. Using this tem-

perature in our equation gives about 450,000 lbs. passing through the condenser. The whole amount needed depends, of course, on the time required for the water to circulate through the condenser and cooler. If the whole time occupied is four hours, and the water makes a complete circuit once in fifteen minutes, only one-sixteenth of the amount mentioned, or about 28,000 lbs., will be needed. This result neglects the amount lost by evaporation in the process of cooling, which is very variable and difficult to compute.

APPENDIX H

HEIGHT OF SPLASHES

The droplets flung upward from the surface of the boiling liquid have a velocity, c, depending on the violence of the boiling. They are pulled downward by gravity. At any time, t, after they start upward, the velocity due to this force is gt; but, because this is directed downward, it is $-gt$. If there were no other forces at work, the velocity at the time t would be $c - gt$. But the current of vapor exerts pressure on the droplets, this pressure being upward or downward, depending on the relative velocity of drop and vapor. The velocity imparted by the pressure of the current of vapor will be greater when the rate of boiling is greater, and will depend also on the specific gravity of the drops, being less when the drops are heavier. This last-mentioned fact accounts for the smaller risk of loss by splashing during the later stages of condensing, when the specific gravity of the milk is relatively high. Since the height to which the drops can rise depends on their velocity upward, the height of the splashing diminishes as the condensing proceeds.

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(Asterisks denote illustrations)

Q

R